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Outcomes of Anesthesiologist-Led Care of Patients Following Liver Transplantation During the COVID-19 Pandemic

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Background: During the COVID-19 pandemic, anesthesiologists were redeployed as transplant ICU intensivists and a postanesthesia care unit was converted to a novel transplant ICU. This study compared the outcomes of patients undergoing liver transplantation under the new model with the prepandemic model.

Methods: Adult patients who underwent liver transplantation at an urban tertiary care center in the United States from December 28, 2015, through May 1, 2020, were identified and grouped according to date of procedure. Peri-COVID cases included transplants that were performed after March 3, 2020. Transplants performed before March 3, 2020, served as pre-COVID controls.

Results: A total of 523 liver transplant patients (30 study cases, 493 controls) were included. Kaplan-Meier survival analysis showed no significant difference in novel transplant ICU length of stay (N-TLOS) (median LOS 3.8 vs. 4.5 days, log-rank p = 0.60) and hospital length of stay (HLOS) (median LOS 14.2 vs. 14.5 days, log-rank p = 0.66). Cox proportional hazards regression with inverse probability of treatment weighting showed no difference in N-TLOS (hazard ratio [HR] 0.91, 95% confidence interval [CI] 0.67–1.23, p = 0.55) or HLOS (HR 0.90, 95% CI 0.65–1.25, p = 0.52). In addition, there were no significant differences (pre-COVID vs. COVID) in time to extubation (median [interquartile range] 28.7 [20.6–50.7] vs. 26.8 [17.4–40.8] hours, p = 0.35), one-year patient survival (12.0% vs. 6.7%, p = 0.055), one-year graft survival (13.4% vs. 6.7%, p = 0.43), and readmission to the ICU (15.0% vs. 20.0%, p = 0.68).

Conclusion: Care provided by non-intensivist anesthesiologists to patients undergoing orthotopic liver transplantation during a pandemic emergency resulted in outcomes similar to those of care provided by intensivists.

The novel coronavirus infectious disease 2019 (COVID-19) and the ensuing pandemic has affected US healthcare systems, necessitating the reallocation of healthcare resources to meet new systemwide demands. COVID-19 has disproportionately affected specific patient populations, including the elderly, patients with comorbid medical conditions, and the immunocompromised, in whom COVID-19 is associated with increased risk of severe morbidity and mortality. Providing safe and adequate non-COVID-19–related medical services for patients who fall into these high-risk categories is a major concern and a complex issue for many tertiary medical centers.

Concern for increased mortality from COVID-19 among immunocompromised patients likely contributed to a nationwide reduction in solid organ transplantation (SOT), including heart, kidney, and liver, at the start of the pandemic. As hospitalizations rapidly increased, the reallocation of intensivists and ICU beds to care for COVID-19 patients also played a role in reducing SOT. During the initial months of the pandemic in the United States, February 6, 2020, through April 4, 2020, data from the United Network for Organ Sharing revealed a 51.1% reduction in deceased donor organ transplantations. Concurrently, March 3, 2020, through April 30, 2020, liver transplant centers in states with the highest incidence of COVID-19 hospitalizations experienced a 59% increase in waitlist mortality. Because of this, the American Association for the Study of Liver Diseases recommended the implementation of new protocols to allow for continued liver transplantation amid the COVID-19 pandemic.

This study outlines the approach taken at a major tertiary academic medical center in New York City for continuing to provide orthotopic liver transplantation (OLT) services throughout the early phase of the COVID-19 pandemic. In addition, it examines the effect of hospital workflow adjustments on postoperative outcomes, including novel transplant ICU length of stay (N-TLOS) and hospital length of stay (HLOS) in patients undergoing OLT during the COVID-19 pandemic.

METHODS

This retrospective study was approved with a waiver of informed consent from the Program for the Protection of Human Subjects at the Icahn School of Medicine at Mount Sinai. The study was conducted according to the Declaration of Helsinki, and all authors certify that the Human Subjects Protection Committee approved the study.
Sinai (Institutional Review Board study number STUDY-20-00629-CR001). In addition, a separate COVID-19 research committee reviewed and approved this study. This manuscript adheres to the applicable Consensus-based Clinical Case Reporting (STROBE) guidelines.\textsuperscript{15}

**COVID Transplant Care Model**

Between March 3, 2020, and May 1, 2020, our institution implemented a series of multidisciplinary changes that allowed the transplant program to continue functioning within the constraints imposed by the COVID-19 pandemic. The changes can be generalized into three broad categories: (1) resource allocation, (2) infection prevention, (3) transplant candidate and donor selection.

**Resource Allocation.** In response to a rapid increase in COVID-19 admissions requiring ICU care, our institution’s 12-bed transplant ICU (TICU) was converted to a COVID-19–only unit. In addition, all fellowship-trained intensivists, critical care fellows, and mid-level providers who normally staff the TICU were redistributed throughout the hospital system to staff COVID-19 units. New multidisciplinary workflows were implemented in accordance with our institution’s COVID-19 infection prevention protocol to maintain the safety of staff and patients.

Following the New York State–directed suspension of elective surgery in March 2020, one of the three isolated postanesthesia care units (PACUs) was repurposed to serve as a fully functional “novel” TICU (N-TICU), and designated as a 12-bed COVID-19–free ICU. Due to concerns regarding proper sterilization of COVID-19–contaminated materials, all monitors, ventilators, and medical equipment used in the design of the N-TICU were strictly prohibited from being recirculated into the general supply. Beds were spaced out by at least six feet and separated by curtains. In addition, two sinks were retrofitted to allow for hemodialysis and continuous veno-venous hemofiltration to be performed in-unit.

A total of four non-intensivist, liver transplant–specialized anesthesiologists were assigned to staff the N-TICU on a rotating schedule. Days were split into 12-hour shifts with an attending assigned to both the day and night shifts. Two anesthesia residents (one senior and one junior) and a mid-level provider with prior ICU experience were also assigned to each 12-hour shift. The N-TICU staffing ratios mirrored our institution’s traditional TICU staffing ratios, with the exception of a critical care fellow being replaced by a mid-level provider.

In the first 24 hours post-transplant, patients were cared for in a 1:1 ICU–trained nurse-to-patient ratio. On postoperative day two, patients were designated as either high or low acuity. High-acuity patients continued to receive coverage by ICU–trained nurses at a 1:1 nurse-to-patient ratio, while low-acuity patients were covered by PACU–trained nurses at a 1:2 nurse-to-patient ratio. All personnel assigned to the N-TICU were not assigned other units for the duration of the study period. These nurse-to-patient ratios were consistent with those of our institution’s traditional TICU.

**Infection Prevention.** All transplant candidates were required to demonstrate two negative COVID-19 reverse transcriptase polymerase chain reaction (RT-PCR) nasopharyngeal tests prior to admission to the N-TICU. An additional negative COVID-19 RT-PCR test in the immediate preoperative period, as well as a thorough assessment ruling out signs or symptoms of infection, were required prior to transplantation. Following surgery, OLT patients were transferred directly from the operating room to the N-TICU. During the pre- and postoperative periods, all patients admitted to the N-TICU underwent daily screening for signs and symptoms of COVID-19 infection. Any patient with new symptoms, including cough, dyspnea, fever, and chills, underwent additional COVID-19 RT-PCR testing. Noncontrast chest computed tomography (CT) was employed in select cases to assess for COVID-19 infection when nasopharyngeal RT-PCR testing was negative but the clinical picture was highly suspicious for infection. In the event of a positive test or presence of concerning findings on pulmonary imaging, the patient was immediately transferred to a COVID-19 designated unit. Patients who tested positive for COVID-19 were deferred for transplantation until the resolution of their infection as defined by two negative RT-PCR tests as well as a CT demonstrating no active pulmonary findings. Regardless of prior testing status, all patients undergoing transplantation were required to undergo rapid COVID-19 testing with a negative test within 48 hours of surgery. See Figure 1 for an outline of the COVID-19 screening algorithm implemented during this period.

Given the unknown effects of COVID-19 on organ viability and graft function, organ procurements were restricted to COVID-19–negative donors. All donors were screened via nasopharyngeal swab with RT-PCR testing and chest CT to rule out infection. It was required that both tests were negative to accept the donor graft.

To reduce risk of exposure for both patients and providers, all meetings, including multidisciplinary rounds, recipient selection, educational conferences, and family meetings, were held virtually. All screening visits for outpatient OLT referrals as well as postdischarge visits following transplantation were performed remotely using a HIPAA-secure video platform. In-person visitation was suspended for all adult patients. Staff members were required to wear N95 masks, eye protection, and scrubs while working in patient-facing areas. Upon entry to any hospital facility, staff members were required to fill out an electronic survey that screened for symptoms related to COVID-19 as well as exposure status. As an additional safety measure, staff underwent temperature checks prior to entry into the N-TICU. Any staff member who experienced an asymp-
tomato exposure or reported symptoms related to COVID-19 were screened for COVID-19 with a SARS-CoV-2 RT-PCR test. Symptomatic staff members were required to quarantine until results were available. In the event of a positive test, staff members were quarantined for a minimum of 10 days from symptom onset, and not allowed to return to work until cleared by Employee Health Services.

Transplant Candidate and Donor Selection. With the exception of deferring COVID-19–positive patients, no changes were made to the institution’s standard candidate selection criteria. Although efforts were made to prioritize transplantation in high-risk candidates, including those with hepatocellular carcinoma, Model for End-Stage Liver Disease (MELD) score > 30, and patients in fulminant hepatic failure, all candidates were considered for transplantation. Living donor liver transplantation (LDLT) was temporarily suspended from March 23, 2020, until May 1, 2020.

Clinical Considerations. Several measures were taken to mitigate the potential risk of staffing the N-TICU with non–ICU trained anesthesiologists. Clinical decision-making was guided largely by preestablished care bundles, which were identical to those that were implemented for the postoperative management OLT patients prior to the COVID-19 pandemic. These care bundles were integrated into the electronic health record infrastructure, thereby serving as a clinical decision support tool. Regular administrative meetings were held to ensure care bundle compliance.

A multidisciplinary approach was used in the management of the N-TICU. In addition to the primary teams, morning rounds were attended by hepatology and nephrology attendings who played an active role in the management of patients during the perioperative period. Transplant surgery, infectious disease, and critical care medicine were all immediately available for consultation.

Financial Considerations. As our institution is a Medicare-approved hospital, inpatient admissions for patients undergoing OLT are reimbursed through the Inpatient Prospective Payment System (IPPS). Under IPPS, each case is assigned a diagnosis-related group (DRG). Each DRG has an associated cost weight that is assigned by the Centers for Medicare & Medicaid Services. The DRGs assigned to a particular admission are determined...
by the ICD-10 and Current Procedural Terminology (CPT) codes that are associated with said admission. The CPT and ICD-10 codes associated with an admission do not differ between a traditional and virtual ICU model. Furthermore, under the current Medicare Physician Fee Schedule, anesthesiology falls under one of several specialties that can be billed for using intensivist CPT professional codes. Therefore, the implementation of a non-intensivist, anesthesiologist-led N-TICU model did not affect reimbursement for OLT-related admissions as compared to the standard pre-COVID care-model.

**Study Population and Data Collection**

Adult patients who underwent OLT from December 28, 2015, through May 1, 2020, were identified and screened for enrollment, including simultaneous liver-kidney transplants and retransplant cases. Transplants that occurred during the COVID period (March 3, 2020–May 1, 2020) were included as our study cases. Transplants that occurred in the pre-COVID period (December 28, 2015–March 3, 2020) were included as controls.

Patient characteristics associated with liver transplantation outcomes were retrieved from departmental and hospital warehouses as well as electronic health records. These data were used as covariates in subsequent analyses and included patient demographics such as age, gender, and body mass index (BMI), as well as medical comorbidities, including coronary artery disease, cardiac arrhythmias, hypertension, diabetes mellitus, and chronic kidney disease.

Liver disease characteristics such as alcoholic cirrhosis, ascites, spontaneous bacterial peritonitis, variceal bleed, hepatic encephalopathy, hepatocellular carcinoma, hepatorenal syndrome, and MELD score were included. In addition, transplantation characteristics such as transplant type, retransplant, and donor type were included.

**Outcome Measures**

Primary outcomes included N-TICU length of stay (N-TLOS) and hospital length of stay (HLOS). N-TLOS was defined as the number of days spent in the N-TICU following OLT. HLOS was defined as the total number of days spent in the hospital following OLT. Days spent in the hospital prior to transplantation were not considered when calculating N-TLOS and HLOS. The independent variable of interest was date of transplant—pre-COVID vs. COVID. Secondary outcomes included time to extubation, one-year patient survival, one-year graft survival, and readmission to the ICU.

**Statistical Analysis**

In this descriptive analysis, a two-sided $t$-test or Kruskal-Wallis test for continuous variables and a chi-square test or Fisher’s exact test for discrete variables were used to assess for differences in characteristics between groups, as appropriate. Kaplan-Meier curves and log-rank tests were used to assess for differences in N-TLOS and HLOS.

Propensity score modeling with inverse probability of treatment weighting (IPTW) was used to determine the association between N-TICU care during the COVID period with N-TLOS and HLOS as compared to traditional ICU care during the pre-COVID period. IPTW is a technique for estimating exposure effect standardized to a pseudo-population that removes confounding in observational studies. It relies on building a penalized logistic regression model with Firth’s bias reduction method to estimate the probability of the COVID period exposure for each individual, and, in subsequent analyses, using the inverse of the predicted probability as a weight. The penalized logistic regression model considered patient demographics and medical comorbidities along with liver disease characteristics, transplantation characteristics, and four categories of MELD scores (MELD $<$ 20, MELD 20–29, MELD 30–39, MELD $>$ 40). MELD scores calculated within one week of OLT, as opposed to MELD-Na, were used for this analysis. The inverse of the individual propensity score was assigned as weight for the patients in the COVID period, whereas the inverse of the 1 minus individual propensity score was assigned as weight for the patients in the pre-COVID period.

In addition, several propensity score models were explored to determine the robustness of our results. To address extremely large or small propensity scores and the resulting extreme weights that may unduly influence results and yield estimates with high variance, we obtained stabilized weights to produce a suitable estimation of the variance of the main effect. However, the distribution of stabilized weights is still influenced by large weights for individual patients and large variability in the estimated treatment effect. Thus, we also employed a weight trimming approach to reduce weights greater than the 95th quantile to the 95th quantile and weights smaller than the 5th quantile to the 5th quantile to improve the performance of propensity score weighting. Finally, we ran each model with and without further adjustment with covariates for intracardiac defibrillator, hepatopulmonary syndrome, and portopulmonary hypertension—extremely rare factors that were not considered in the propensity score models, as they caused model instability.

All analyses were performed with RStudio with R v4.1.1. (RStudio Team, Boston). Cox proportional hazards regression analysis was used to evaluate the influence of workflow changes on N-TLOS and HLOS for post–liver transplant patients. All analyses included robust standard error calculations.

**RESULTS**

Of 554 patients who underwent OLT between December 2015, and May 2020, 521 transplants occurred in the pre-COVID era; 33 transplants occurred in the COVID era. After removal of 25 patients due to incomplete datasets
Table 1. Comparison of Patient Demographic Data Among Liver Transplant Patients

|                              | Pre-COVID (n = 493) | COVID (n = 30) | P value* |
|------------------------------|---------------------|----------------|----------|
| Age, years, mean (SD)        | 54.8 (12.9)         | 52.8 (15.3)    | 0.48     |
| Male, n (%)                  | 324 (65.7)          | 18 (60.0)      | 0.56     |
| BMI, kg/m², mean (SD)        | 28.1 (5.9)          | 29.2 (7.0)     | 0.45     |
| Liver disease subtype, n (%) |                     |                |          |
| Alcoholic cirrhosis          | 29 (5.9)            | 13 (43.3)      | < 0.001  |
| Hepatocellular carcinoma     | 79 (16.0)           | 8 (26.7)       | 0.13     |
| Liver disease characteristics, n (%) |       |                |          |
| Ascents                      | 14 (2.8)            | 21 (70.0)      | < 0.001  |
| Spontaneous bacterial peritonitis | 34 (6.9)         | 10 (33.3)      | < 0.001  |
| Vascular bleed               | 17 (3.4)            | 17 (56.7)      | < 0.001  |
| Hepatic encephalopathy       | 34 (6.9)            | 16 (53.3)      | < 0.001  |
| Hepatorenal syndrome         | 7 (1.4)             | 5 (16.7)       | < 0.001  |
| MELD score                   |                     |                |          |
| MELD < 9                     | 141 (28.6)          | 8 (26.7)       |          |
| MELD 10 to 19                | 105 (21.3)          | 13 (43.3)      |          |
| MELD 20 to 29                | 110 (22.3)          | 5 (16.7)       |          |
| MELD ≥ 30                    | 137 (27.8)          | 4 (13.3)       |          |
| Medical comorbidities, n (%) |                     |                |          |
| Coronary artery disease      | 15 (3.0)            | 4 (13.3)       | 0.02     |
| Cardiac arrhythmias          | 9 (1.8)             | 3 (10.0)       | 0.03     |
| Hypertension                 | 109 (22.1)          | 14 (46.7)      | 0.01     |
| Chronic kidney disease       | 22 (4.5)            | 10 (33.3)      | < 0.001  |
| Type 2 diabetes mellitus     | 90 (18.3)           | 9 (30.0)       | 0.15     |
| Transplantation characteristics, n (%) |       |                |          |
| History of prior transplant  | 34 (6.9)            | 1 (3.3)        | 0.71     |
| Simultaneous liver-kidney transplant | 58 (11.8)     | 5 (16.7)       | 0.39     |
| Donor type                   |                     |                | < 0.001  |
| Deceased, circulatory death  | 24 (4.9)            | 8 (26.7)       |          |
| Deceased, brain death        | 418 (84.8)          | 19 (63.3)      |          |
| Living                       | 51 (10.3)           | 3 (10.0)       |          |

* “P value” refers to the statistical significance of differences between the two groups, assessed by t-test for age, body mass index (BMI), and length of stay; and by chi-square test or Fisher’s exact test for the remaining variables. SD, standard deviation; MELD, Model for End-Stage Liver Disease.

and 6 patients with rare factors for the cohort (intracardiac defibrillator, hepatopulmonary syndrome, or portopulmonary hypertension), IPTW yielded a final sample of 30 cases and 493 controls.

Table 1 displays group characteristics. There were no statistically significant differences in age, sex, BMI, N-TLOS, and HLOS between groups. There were also no differences in history of prior OLT or occurrence of simultaneous liver-kidney transplant. The prevalence of coronary artery disease, cardiac arrhythmias, hypertension, and chronic kidney disease, as well as liver disease characteristics such as alcoholic cirrhosis, ascites, spontaneous bacterial peritonitis, variceal hemorrhage, hepatic encephalopathy, and hepatorenal syndrome, were higher in the COVID cohort. There was a significant difference between MELD scores among the COVID and pre-COVID cohorts. The prevalence of type 2 diabetes mellitus and hepatocellular carcinoma was not significantly different between the two groups. There was a higher incidence of donation following brain death among pre-COVID cases and a higher incidence of donation following circulatory death among COVID cases.

Figures 2 and 3 display the Kaplan-Meier survival curves of N-TLOS and HLOS, respectively. The median (interquartile range [IQR]) N-TLOS and HLOS were 3.8 (2.6–6.8) days and 14.2 (9.7–23.9) days in the pre-COVID group, and 4.5 (3.0–6.8) days and 14.5 (12–34) days in the COVID group. The differences were not statistically significantly (N-TLOS log-rank p = 0.60 and HLOS log-rank p = 0.66) (Table 2). The median time to exubation for the pre-COVID and COVID groups was 28.7 (20.6–50.7) and 26.8 (17.4–40.8) hours, respectively (p = 0.35). There were no significant differences (pre-COVID vs. COVID) in one-year patient survival (12.0% vs. 6.7%, p = 0.055), as well as one-year graft survival (13.4% vs. 6.7%, p = 0.43). In addition, when comparing the pre-COVID and COVID group, there was no significant difference in readmission to the ICU (15.0% vs. 20.0%, p = 0.68) (Table 3). Of the 30 patients who underwent OLT during the study period, 2 tested positive for COVID-19 during their postoperative course.

The traditional multivariable Cox regression revealed no significant association between the COVID era and N-TLOS when compared with pre-COVID era (hazard ra-
Figure 2: Shown here is the Kaplan-Meier survival curve of novel transplant ICU (N-TICU) length of stay (N-TLOS) for pre-COVID and COVID groups following orthotopic liver transplantation (OLT). The light blue band demonstrates the confidence intervals for the COVID group; the light red band demonstrates the confidence intervals for the pre-COVID group. These results demonstrate that there was no significant difference between TICU length of stay when comparing the COVID and pre-COVID cohorts.

Figure 3: The graph shows the Kaplan-Meier survival curve of hospital length of stay for pre-COVID and COVID groups following orthotopic liver transplantation (OLT). The light blue band demonstrates the confidence intervals for the COVID group; the light red band demonstrates the confidence intervals for the pre-COVID group. These results demonstrate that there was no significant difference between hospital length of stay when comparing the COVID and pre-COVID cohorts.
Table 2. Primary Outcome Measures

|                  | Pre-COVID (n = 493) | COVID (n = 30) | P value* |
|------------------|---------------------|---------------|----------|
| N-TLOS, median (IQR) | 3.8 (2.6–6.8)       | 4.5 (3.0–6.8) | 0.60     |
| HLOS, median (IQR)  | 14.2 (9.7–23.9)     | 14.5 (12–34)  | 0.66     |

* "P value" refers to the statistical significance of differences between the two groups assessed by the log-rank test. N-TLOS, novel TICU (transplant ICU) length of stay; IQR, interquartile range; HLOS, hospital length of stay.

Table 3. Secondary Outcome Measures

|                  | Pre-COVID (n = 493) | COVID (n = 30) | P value* | Total (N = 523) |
|------------------|---------------------|---------------|----------|-----------------|
| Time to extubation |                    |               |          |                 |
| Median (IQR)     | 28.7 (20.6–50.7)    | 26.8 (17.4–40.8) | 0.35    | 28.5 (20.0–50.6) |
| Missing data, n (%) | 98 (19.9)       | 3 (10.0)       |          | 101 (19.3)       |
| 1-year patient survival, n (%) | |                 |          |                 |
| Survival > 1 year | 430 (87.2)        | 28 (93.3)      | 0.55     | 458 (87.6)       |
| Survival < 1 year | 59 (12.0)         | 2 (6.7)        |          | 61 (11.7)        |
| Missing         | 4 (0.8)           | 0 (0)          |          | 4 (0.8)          |
| 1-year graft survival, n (%) | |                 |          |                 |
| Survival > 1 year | 423 (85.8)        | 28 (93.3)      | 0.43     | 451 (86.2)       |
| Survival < 1 year | 66 (13.4)         | 2 (6.7)        |          | 68 (13.0)        |
| Missing         | 4 (0.8)           | 0 (0)          |          | 4 (0.8)          |
| Readmission to ICU, n (%) | |                 |          |                 |
| No              | 405 (82.2)        | 24 (80.0)      | 0.68     | 429 (82.0)       |
| Yes             | 74 (15.0)         | 6 (20.0)       |          | 80 (15.3)        |
| Missing         | 14 (2.8)          | 0 (0)          |          | 14 (2.7)         |

* "P value" refers to the statistical significance of differences between the two groups assessed by the Kruskal-Wallis test for time to extubation, and by chi-square test for the remaining variables. IQR, interquartile range.

Table 4. Cox Proportional Hazards Regression Analysis for TICU and Hospital LOS

| Models                                      | TLOS HR* (95% CI) | P value | HLOS HR* (95% CI) | P value |
|---------------------------------------------|-------------------|---------|-------------------|---------|
| Traditional approach without IPTW           |                   |         |                   |         |
| Pre-COVID liver transplants                 | Reference         |         | Reference         |         |
| COVID liver transplants                     | 0.63 (0.37–1.07)  | 0.09    | 0.66 (0.38–1.16)  | 0.15    |
| After IPTW with stabilized weights only     |                   |         |                   |         |
| Pre-COVID liver transplants                 | Reference         |         | Reference         |         |
| COVID liver transplants                     | 0.92 (0.56–1.50)  | 0.73    | 0.85 (0.56–1.29)  | 0.44    |
| After IPTW with stabilized and trimmed weights |               |         |                   |         |
| Pre-COVID liver transplants                 | Reference         |         | Reference         |         |
| COVID liver transplants                     | 0.91 (0.67–1.23)  | 0.55    | 0.90 (0.65–1.25)  | 0.52    |

* Hazard ratio (HR) represents the relative probability of hospital discharge at any given time during TICU or hospitalization. HR > 1 means more likely to be discharged early than the reference group. TICU, transplant ICU; LOS, length of stay; TLOS, TICU length of stay; HLOS, hospital length of stay; IPTW, inverse probability treatment weighting.

tio [HR] 0.63; 95% confidence interval [CI] 0.37–1.07, p = 0.09). There was no difference in HLOS between groups (HR 0.66; 95% CI 0.38–1.16, p = 0.15) (Table 4). The Cox regression analysis with IPTW with stabilized weights and trimmed weights also demonstrated that there was no significant association between the COVID era cases and N-TLOS (HR 0.91, 95% CI 0.67–1.23, p = 0.55) or HLOS (HR 0.90, 95% CI 0.65–1.25, p = 0.52) when compared to the pre-COVID era controls (Table 4). This lack of statistically significant differences held across a variety of propensity score models (traditional unweighted, stabilized-only, stabilized and trimmed weights, with and without adjustment for rare covariates).

**DISCUSSION**

Despite recommendations against the cessation of OLT during the COVID-19 pandemic and several studies...
demonstrating the ability to continue performing OLT without compromising short-term outcomes.\textsuperscript{23–27} There continued to be a significant reduction in OLT volume past the early stages of the pandemic.\textsuperscript{10,28} In one international survey regarding physician attitudes toward the continuation of SOT during the pandemic, more than 80% of respondents favored the selective or complete cessation of transplant services.\textsuperscript{29} There was also significant variability among transplant centers in their response to the pandemic that could not be explained by regional infection rates alone.\textsuperscript{11} This variability more likely reflected confusion or distrust in federal and state guidelines, as well as center-to-center differences in the prioritization of resources for continued OLT services relative to the management of COVID-19 patients.

In this analysis, we used retrospective data from a single tertiary center in New York City to examine whether the novel workflow changes that were implemented to continue OLT during the first peak of the COVID-19 pandemic were associated with a difference in outcomes. We collected data on several short-term outcomes, including N-TLOS, HLOS, time to exubation, and readmission to the ICU. Long-term outcomes, including one-year patient survival and one-year graft survival, were also analyzed. The results failed to demonstrate a statistically significant difference in any of the short- or long-term outcome measures when comparing the pre-COVID and COVID groups. These data suggest that it was possible to continue performing OLT safely during the height of the COVID-19 pandemic.

Consistent with other recent publications,\textsuperscript{12,15–19,22} the present study analyzed workflow changes to accommodate liver transplantation while in the midst of the COVID-19 pandemic. Centers varied in their approach, but interventions were primarily focused on the redistribution of available resources, infection prevention, and recipient-donor selection. Several institutions reported the use of COVID-19–free spaces for the inpatient management of transplant patients.\textsuperscript{23,26} However, the ability to maintain COVID-19–free transplant units likely varied given center-to-center differences in resource availability as well as regional differences in hospitalizations related to COVID-19. Following a rapid increase in ICU capacity, two New York City transplant centers reported being unable to maintain all transplant patients in COVID-19–free units.\textsuperscript{30} Here, converting one of our institution’s PACUs into a designated COVID-19–free unit capable of providing post-OLT care allowed for the continued care of immunosuppressed transplant patients.

Although much of the literature does not describe staffing changes during this time, one hospital in Westchester, New York, did report that transplant surgeons assumed the care of patients during the postoperative period.\textsuperscript{30} Here, transplant-specialized non-intensivist anesthesiologists assumed the care of patients undergoing OLT, allowing intensivists to focus on the management of COVID-19 patients. The anesthesiologists assigned to the N-TICU were not exposed to COVID-19 patients. This staffing change likely reduced the chance of provider-to-patient transmission.

Similar infection prevention measures were reported by institutions that continued to provide transplant services throughout the COVID-19 pandemic. Strategies included symptomatic and asymptomatic testing policies for clinical personnel,\textsuperscript{24,26} required quarantine in the event of a positive result,\textsuperscript{26} the use of virtual meeting platforms to limit in-person interaction,\textsuperscript{24–27,30} and either the suspension of or a significant reduction in visiting hours.\textsuperscript{23,25,26} Several institutions also reported the use of a remote meeting platform for the outpatient screening of transplant referrals\textsuperscript{24,27} as well as for completion of postdischarge follow-up visits.\textsuperscript{24} In most cases, institutions required RT-PCR testing for COVID-19 as well as thoracic imaging to rule out a false negative infection in both donors and recipients.\textsuperscript{23–27} Various protocols for regular symptomatic monitoring with repeat testing for hospitalized patients were also reported.\textsuperscript{23–27}

Most institutions refused grafts from COVID-19–positive donors,\textsuperscript{23,24,26,27} and although there was some variation, in most cases OLT was deferred in recipients who tested positive for COVID-19.\textsuperscript{23,26,27} In addition, several centers reported the temporary suspension of their living donor liver transplantation (LDLT) programs.\textsuperscript{26,27} One center that did continue to provide LDLT instituted a mandatory three-month postponement if donors tested positive for COVID-19.\textsuperscript{23} In extenuating circumstances, when COVID-19 serology could not be obtained prior to surgery, one center proceeded with OLT in asymptomatic patients provided N95 respirators were worn by all staff members.\textsuperscript{24}

In addition to COVID-19 status, acuity was considered in the selection of transplant recipients. Citing concerns over ICU bed and ventilator availability, several centers opted to defer transplantation in patients perceived to have a high risk of post-transplant mortality and therefore likely to experience a prolonged hospital stay.\textsuperscript{24,26} One center noted that patients without cardiac and respiratory comorbid conditions were preferentially listed.\textsuperscript{24} Conversely, several institutions opted to prioritize transplantation in high-risk patients whose three-month risk of mortality related to liver disease exceeded that of mortality related to COVID-19.\textsuperscript{30} Similarly, one study noted the temporary suspension of nonurgent cases, citing the same concerns regarding resource utilization.\textsuperscript{27} Although we did prioritize transplantation in patients with high mortality risk from liver disease, we did not take additional measures to suspend nonurgent cases. Because we chose not to delay transplantation on the basis of acuity or anticipated LOS, converting our PACU into a COVID-19–free unit designated for post-transplant care allowed for the space and staffing needed to care for these patients.
Optimal resource utilization and careful triage should be the guiding principles of patient care during a pandemic. The decision to continue providing high-resource-utilizing services, such as OLT, should be made after careful consideration of the unique risks and benefits in doing so. Concern for a potential association between increased mortality from COVID-19 and factors such as reduced ICU bed capacity and nursing availability likely influenced decisions regarding the suspension of transplant programs. Increased risk of mortality from infection among immunosuppressed patients was an additional consideration among institutions that were unable to provide COVID-19–free spaces for post-transplant care. Furthermore, a nationwide reduction in blood donation likely led to concern over maintaining adequate supply.

The impact of differing strategies employed to triage OLTs has yet to be seen. For example, the preferential selection of low-acuity cases may lead to increased waitlist mortality among more critically ill patients. On the contrary, as transplant rates return to normal, a subsequent reduction in graft availability may also lead to increased mortality among low-acuity patients in whom transplantation was delayed. Given these risks, it is important that centers work together to ensure that SOT can continue safely. In one study, Michaels et al. suggest the redistribution of wait-listed patients located in endemic regions to centers in less affected areas. Doing so would require a high level of coordination between institutions, but it would also help limit the potential for regional disparities in care.

This study was unique in its description of non-intensivist anesthesiologist–led peri-transplant care. Despite the clinicians’ lack of formal ICU training, the care that was provided during this time did not come at the expense of either short- or long-term outcomes. Anesthesiologists are experts in physiology, including cardiopulmonary pathophysiology and resuscitation, mechanical ventilation, and caring for critically ill patients in the operating room and PACU. Despite this, the relative percentage of anesthesiologists who practice critical care medicine in the United States is low. Given the current shortage of critical care physicians in the United States, processes that facilitate the more active participation of anesthesiology departments in critical care settings, particularly as it pertains to surgical critical care, may help to address the shortage.

Limitations

In designing this study, we attempted to limit potential sources of bias in the selection process. However, because of a relatively short study window, our results may have been biased by the small cohort of cases vs. controls. This issue was addressed by using multiple propensity score models to analyze our primary outcome measures, N-TLOS and HLOS. Given the retrospective nature of this study, it was difficult to control for all the demographic characteristics of our cohort. There was a higher instance of comorbid conditions among the COVID cohort as compared to the pre-COVID controls. In addition, there was a higher incidence of donation following circulatory death among peri-pandemic cases, while there was a higher incidence of donation following brain death among pre-pandemic cases. Although these differences introduce a potential source of bias, we would have expected the effect to work against our findings. Despite increased comorbid conditions and higher incidence of donation following circulatory collapse among the cohort of interest, there was no significant difference in both primary, and secondary outcome measures. Finally, this study was performed at a large tertiary academic medical center located in an urban setting. Therefore, these findings should be interpreted within the context of the setting in which they were produced.

CONCLUSION

Our results suggest that during the initial wave of the COVID-19 pandemic, non-intensivist anesthesiologist–led care was associated with favorable post-OLT outcomes. This suggests that in future emergency events, utilization of this care model would allow for the continuation of OLT without compromising quality of care.

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