Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Inferior Liver Transplant Outcomes during early COVID-19 pandemic in United States

Kenji Okumura\textsuperscript{a,∗}, Seigo Nishida\textsuperscript{a}, Hiroshi Sugawara\textsuperscript{a}, Gregory Veillette\textsuperscript{a}, Roxana Bodin\textsuperscript{a, b}, David C. Wolf\textsuperscript{a, b}, Abhay Dhand\textsuperscript{a, b}

\textsuperscript{a} Department of Surgery, Westchester Medical Center / New York Medical College, Valhalla, NY, USA
\textsuperscript{b} Department of Medicine, Westchester Medical Center / New York Medical College, Valhalla, NY, USA

\textsuperscript{∗} Corresponding author: 100 Woods Road, 10595, Phone: +1(914) 493-8099/ Fax: +1 (914) 493-1679
\textit{E-mail address:} kenji.okumura@wmchealth.org (K. Okumura).

\begin{abstract}
\textbf{Background:} Since its declaration as a global pandemic on March 11th, 2020, COVID-19 has had a significant effect on solid-organ transplantation. The aim of this study was to analyze the impact of COVID-19 on Liver transplantation (LT) in United States.

\textbf{Methods:} We retrospectively analyzed the United Network for Organ Sharing database regarding characteristics of donors, adult-LT recipients, and transplant outcomes during early-COVID period (March 11 - September 11, 2020) and compared them to pre-COVID period (March 11 - September 11, 2019).

\textbf{Results:} Overall, 4% fewer LTs were performed during early-COVID period (4107 vs 4277). Compared to pre-COVID period, transplants performed in early-COVID period were associated with: increase in alcoholic liver disease as most common primary diagnosis (1315 vs 1187, \textit{P}<0.01), higher MELD score in the recipients (25 vs 23, \textit{P}<0.01), lower time on wait-list (52 vs 84 days, \textit{P}<0.01), higher need for hemodialysis at transplant (9.4 vs 11.1, \textit{P}<0.01), longer distance from recipient hospital (131 vs 64 miles, \textit{P}<0.01) and higher donor risk index (1.65 vs 1.55, \textit{P}<0.01). Early-COVID period saw increase in rejection episodes before discharge (4.6 vs 3.4, \textit{P}=0.023) and lower 90-day graft/patient survival (90.2 vs 95.1 \%, \textit{P}<0.01; 92.2 vs 96.5 \%, \textit{P}<0.01). In multivariable cox-regression analysis, early-COVID period was the independent risk factor for graft failure at 90-days post-transplant (Hazard Ratio 1.77, \textit{P}<0.01).

\textbf{Conclusions:} During early-COVID period in United States, overall LT decreased, alcoholic liver disease was primary diagnosis for LT, rate of rejection episodes before discharge was higher and 90-days post-transplant graft survival was lower.

© 2022 The Author(s). Published by Elsevier Masson SAS. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)
\end{abstract}

\textbf{Background}

Starting in late December 2019, Coronavirus disease 2019 (COVID-19) had an explosive spread around the world [1]. COVID-19 pandemic significantly impacted solid-organ transplantation with increased mortality seen in patients on the waitlist and in transplant recipients [2]. Despite the declaration of national emergency, closure of non-essential businesses, and aggressive social distancing measures, we saw a rapid transmission of COVID-19 across United States. During the initial part of the pandemic, the numbers of waitlist registrations and organ donations significantly decreased, which was much more pronounced for kidney transplantation [3–5]. After a brief pause, various centers resumed performing transplantation, albeit cautiously, in selected recipients [6]. The early-COVID period also coincided with the implementation of the new national liver allocation policy [7]. The data regarding outcomes of liver transplantation (LT) performed during the COVID 19 pandemic is limited. The aim of this study was to analyze the impact of COVID-19 pandemic on LT and its outcomes in the US.

\textbf{Material and Methods}

\textbf{Patients and selection criteria}

Patient-level non-identifiable information was retrieved from the nationwide Organ Procurement and Transplant Network managed by

\textbf{Abbreviations:} ALD, alcoholic related liver disease; ALF, acute liver failure; BMI, body mass index; CI, confidence interval; COD, causes of death; COVID-19, Coronavirus disease 2019; HBV, hepatitis B virus; HCC, hepatocellular carcinoma; HCV, hepatitis C virus; HR, hazard ratio; ICU, intensive care units; IQR, interquartile range; LT, liver transplantation; MELD, model for end-stage liver disease; MV, mechanical ventilation; SARS-CoV-2, severe acute respiratory syndrome coronavirus-2; SE, standard error; UNOS, United Network for Organ Sharing

This work was presented at the Liver meeting 2021.

Available online 16 May 2022

Accepted 15 May 2022

Received 10 April 2022

Article History:

Keywords:
liver transplant recipients
COVID-19 mortality
United Network for Organ Sharing database
graft failure
alcohol related liver disease
COVID-19
liver transplant outcomes
United Network for Organ Sharing
the United Network for Organ Sharing (UNOS). We evaluated all patients 18 years of age and older who underwent LT in the United States between 2019 and 2020. We compared the donor and recipient characteristics and transplant outcomes between pre-COVID period (March 11th to September 11th, 2019) and compared them to early-COVID period (March 11th to September 11th, 2020). If a patient had more than one LT during the time period, only their first transplant was included in analysis. This study was considered exempt by the Institutional Review Board.

Patient characteristics and outcome variables

We searched UNOS registry as of March 2021 for recipient demographic data, primary listing diagnosis, co-morbidities, time on wait-list, model for end-stage liver disease (MELD) scores at time of listing and transplant. Evaluable donor characteristics included demographics, donor risk index [8], cold ischemia time and distance between donor and recipient hospital. Numbers and trends of transplants including deceased donors and living donors in all regions and causes of death (COD) in recipients were also reviewed in the UNOS registry.

Statistics

Statistical analyses were performed using IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA) and R-Studio using R Version 4.1.1 (R Studio, Boston, MA, USA). Non-parametric analysis was used to compare continuous variables between groups (Mann-Whitney U test 2 groups and for categorical data with the χ2 test or Fisher’s exact test for categorical data). The overall and graft survival were calculated from the date of transplant to the date of event using the Kaplan-Meier method. The log-rank test was used to compare survival curves. Cox regression analysis was applied to assess the association of multiple covariate factors with survival between two groups. Results were presented as hazard ratios (HR) and reported with 95% confidence intervals (CI) and two sided P values. The stepwise backward model selection method was used to build the most parsimonious multivariable model. Sensitivity analysis was performed to calculate the E-value [9]. For all statistical analyses, P < 0.05 was taken as statistically significant.

Results

Liver transplants and its trends

Of the 8,384 individuals who received a LT during the study period, there was a 4% cumulative decrease in a number of liver transplants performed during the early-COVID period (4,107 vs 4,277). This decrease was most pronounced in the months of March-April, 2020 with a rebound in numbers seen from May-July, 2020 (Fig. 1A). Number of liver transplantation performed in each UNOS region is shown in Fig. 1B. During the study period, the total number of liver transplantsations decreased in regions 1, 2, 3, 5, 6 and 8 and the number of liver transplantations increased in region 7, 9, 10 and 11.

Recipient Characteristics

Characteristics of LT recipients are summarized in table 1. As the primary etiology, the number and percentage of alcohol related liver disease (ALD) significantly increased during the early-COVID period [1315 (32%) vs 1187 (28%), while the number of transplants for hepatocellular carcinoma (HCC) significantly decreased [752 (18%) vs 896 (21%)]. During the early-COVID period, the median waiting list time was shorter (52 vs 84 days, P < 0.001), the need for dialysis before transplant was higher (11 vs 9.4%, P = 0.012) and the median MELD score at the time of listing (21 vs 20, P < 0.001) and MELD score at time of transplant were higher (25 vs 23, P < 0.001). For induction immunosuppressive therapy, use of anti-thymocyte globulin decreased (4.6 vs 7.5%, P < 0.001) and use of basiliximab and steroid increased (24.0 vs 20.7%, P < 0.001; 58.5 vs 55.2%, P < 0.001) during the early-COVID period.

Donor characteristics

During the early-COVID period, the donor body mass index (BMI) was higher (27.3 vs 26.9 kg/m2, P = 0.016), while median donor age, gender ratio, number of living donors (4.7 vs 5.1%, P = 0.36) and Hepatitis C virus (HCV) positivity rate (10.3 vs 9.9%, P = 0.55) were the same. During the early-COVID period, median distance between donor hospital and recipient hospital increased (131 vs 64 miles, P < 0.001), cold ischemia time was prolonged (5.7 vs 5.5 hour, P < 0.001), and donor risk index increased (1.65 vs 1.55, P < 0.01). Outcomes

The risk of acute rejection prior to discharge was significantly higher in the early-COVID period (4.6 vs 3.4, P = 0.023) (Table 2). Graft survival at 30-days post-transplantation was statistically lower (95.2 vs 96.6%, P = 0.013), while 30-days patient survival was the same (96.9 vs 97.8%, P = 0.076) during the early-COVID period. Graft survival and patient survival at 90-days post-transplantation were significantly lower during the early-COVID period (90.2 vs 91.1%, P < 0.001; 92.2 vs 96.5%, P < 0.001). This difference became more pronounced after 30 days post-transplantation (Fig. 2A & 2B). COVID-19 was listed as the direct cause of death in 5/155 (3.2%) of total deaths in patients who were transplanted during the early-COVID period. In the cox regression multivariable analysis, early-COVID period (HR 1.77; 95% CI, 1.45-2.17; P < 0.001), recipient portal vein thrombosis (HR 1.48; 95% CI, 1.11-1.99; P = 0.008), recipient mechanical ventilation at the time of transplant (HR 1.70; 95% CI 1.18-2.46; P = 0.005), re-transplant (HR 2.06; 95% CI 1.44-2.96; P < 0.001), HCV-positive donor (HR 0.67; 95% CI, 0.46-0.99; P = 0.043), and cold ischemia time (HR 1.10; 95% CI, 1.06-1.13; P < 0.001) had a significant impact for 90 days graft survival. Other characteristics like recipient age, recipient gender, recipient BMI, pre-transplant diabetes, donor age, donor gender, donor BMI and donor risk index did not impact the outcomes (Table 3).

Sensitivity Analysis

The HR ratio of 1.77 for graft failure could only be explained away by an unmeasured confounder, above and beyond all the currently measured confounders, that was associated with both early-COVID period and 90-day graft loss by a HR of 2.94-fold each. The confidence interval could be moved to include the null only by an unmeasured confounder, above and beyond all the currently measured confounders, that was associated with both early-COVID period and 90-day graft loss by a HR of 2.26-fold each.

Discussion

This study was performed to investigate the impact of COVID-19 pandemic on liver transplantation rates and its outcomes. Using the UNOS database, we describe unique changes in the donor and recipient characteristics, and a higher rate of graft loss during the first 90 days of transplantation during the early-COVID period.

Even before the pandemic, alcohol related liver disease was becoming one of the most common indications of liver transplant in the United States [10]. During the pandemic, overall alcohol consumption and its misuse increased considerably [11, 12]. This led to an increase in hospitalizations from ALD as well as the increase in liver transplants performed for both acute and chronic alcohol...
related liver disease [12]. There was a corresponding decrease in liver transplantations performed for chronic hepatitis-related liver disease and HCC [13, 14].

Very early in the pandemic, due to infectious concerns, most of the transplant centers were performing transplants in fewer and very carefully selected patients [2]. To justify the risk-benefit of performing transplant during a pandemic, these selected patients were usually sicker and had a higher probability of imminent death while waiting for liver transplantation. As previously described in the literature, these sicker patients had an increased need for intensive care and higher incidence of renal dysfunction requiring hemodialysis [15]. This likely resulted in the higher MELD score both at the time
of listing and at the time of transplantation, and a higher incidence of multi-organ (simultaneous liver-kidney) transplants being performed. A decrease in overall wait time during early-COVID period was likely associated with an increase in the number of patients with acute alcoholic liver disease, who because of their progressive and medically non-responsive liver dysfunction, often underwent liver transplantation during their index hospitalization [11]. A decrease in listings and liver transplantsations for HCC may also have contributed to a decrease in median MELD and waitlist times during this period.

The decrease in the frequency of LTs performed in US was worse very early in the pandemic, when transplant community had a poor understanding of the disease, and very limited diagnostic and therapeutic options were available [2]. At the same time healthcare facilities especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources towards the care of patients with COVID, while critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhelmed by critically ill patients with COVID. This lead to diversion of resources especially intensive care units (ICU) were overwhel...
infection (non-COVID) were lower, deaths from primary non-function of the graft, graft failure, bleeding and multi-organ failure increased. (Supplement table 1). This is likely because of a combination of factors. In early part of the pandemic, before the availability of COVID vaccinations, fresh transplant recipients were at a higher risk of acquiring severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) infection. This acquisition could be from household contacts, community spread or possibly from health care exposure. Direct COVID deaths accounted for 3.2% (5/155) of all the deaths during the 90-days post-transplant period for liver transplants performed during the early-COVID period. Immediately after discharge, transplant recipients and delays in obtaining laboratory and imaging testing. As shown in the regression multivariable analysis, other factors that impacted 90-day graft survival were recipient portal vein thrombosis, mechanical ventilation at time of transplant, re-transplantation and longer cold ischemia time. All these known factors along with impact of unknown risks associated with recidivism in patients transplanted for alcoholic liver disease, and long-term impact of increased graft rejection prior to discharge may also have contributed to overall worse 90-day graft and patient survival.

Limitations

This study was performed retrospectively using UNOS database. Only information related to COVID-19 in the database was the cause of death. Other indirect effects of COVID-19 like psychosocial impact, medication non-compliance, rates of recidivism of alcohol use, rates of community/household spread of COVID-19 are not available in the database and may impact the outcomes.

Conclusion

During the early-COVID period (from March 11, 2020 to September 11, 2020), overall number of liver transplantation decreased, alcohol related liver disease became the primary diagnosis for liver transplantation, rate of organ rejection was higher and 90-day post-transplant graft survival was lower. While lessons learnt during this period have helped the transplant community become more resilient, long-term impact on the outcomes of transplants performed during this period need to be further evaluated.

Author contributions to manuscript

KO, SN and AD contributed to study design, analysis of data and writing of the manuscript. All authors approved the final manuscript.

Conflict of interest

The authors have no conflicts to declare.

Acknowledgment

The data reported here have been supplied by the UNOS as the contractor for the OPTN. The interpretation and reporting of these data are the responsibility of the author(s) and in no way should be seen as an official policy of or interpretation by the OPTN or the U.S. Government. We analyzed the data provided by UNOS in March 2021. Authors thank Jonathan Butler, MS (Department of Surgery, New York Medical College, Valhalla, NY) for statistical consultation.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jliver.2022.100099.

References

[1] Bogoch II, Watts A, Thomas-Bachli A, Huber C, Kraemer MU, Khan K. Pneumonia of unknown etiology in Wuhan, China: potential for international spread via commercial air travel. Journal of travel medicine 2020;27 taaa008. 10.1093/jtm/taaa008.
[2] Danziger-Isakov L, Blumberg EA, Manuel O, Sester M. Impact of COVID-19 in solid organ transplant recipients. American Journal of Transplantation 2021;21:925-37. doi:10.1111/ajt.16449.
[3] Boyarsky BJ, Werbel WA, Durand CM, Avery RK, Jackson KR, Kernodle AB, Snyder J, et al. Early national and center-level changes to kidney transplantation in the United States during the COVID-19 epidemic. Am J Transplant 2020;20:3131–9. doi:10.1111/ajt.16167.
[4] Cholangiell G, Podboy A, Alshuwayh OS, Kim D, Kanwal F, Esquiel CO, Ahmed A. Early Impact of COVID-19 on Solid Organ Transplantation in the United States. Transplantation 2020;104:2221–9. doi:10.1097/TP.0000000000003391.
[5] Miller J, Wey A, Musgrove D, Son Ahn Y, Hart A, Kasiske BL, Hirose R, et al. Mortality among solid organ waitlist candidates during COVID-19 in the United States. Am J Transplant 2021;21:2362–8. doi:10.1111/ajt.16550.
[6] Lembach H, Hann A, McKay SC, Hartog H, Vasanth S, El-Dahl P, Murphy N, et al. Resuming liver transplantation amid the COVID-19 pandemic. Lancet Gastroenterol Hepatol 2020;5:725–6. doi:10.1016/S2468-1253(20)30360-5.
[7] Organ Procurement and Transplant Network United Nation for Organ Sharing. In. https://unos.org/news/system-implementation-notice-liver-and-intestinal-organ-distribution-based-on-acytue-circles-implemented-feb-4/ Accessed at April 9th, 2022.
[8] Feng S, Goodrich NP, Bragg-Gresham JL, Dykstra DM, Punch JD, DebRoy MA, Greenstein SM, et al. Characteristics associated with liver graft failure: the concept of a donor risk index. Am J Transplant 2006;6:783–90. doi:10.1111/j.1600-6143.2006.01242.x.

[9] VanderWeele TJ, Ding P. Sensitivity Analysis in Observational Research: Introducing the E-Value. Ann Intern Med 2017;167:268–74. doi:10.7326/M16-2607.

[10] Cholankeril G, Ahmed A. Alcoholic Liver Disease Replaces Hepatitis C Virus Infection as the Leading Indication for Liver Transplantation in the United States. Clin Gastroenterol Hepatol 2018;16:1356–8. doi:10.1016/j.cgh.2017.11.045.

[11] Cholankeril G, Goli K, Rana A, Hernaez R, Podboy A, Jalal P, Da BL, et al. Impact of COVID-19 Pandemic on Liver Transplantation and Alcohol-Associated Liver Disease in the USA. Hepatology 2021;74:3316–29. doi:10.1002/hep.32067.

[12] Bittermann T, Mahmud N, Abt P. Trends in Liver Transplantation for Acute Alcohol-Associated Hepatitis During the COVID-19 Pandemic in the US. JAMA Netw Open 2021;4 e211871310.1001/jamanetworkopen.2021.18713.

[13] Wang S, Toy M, Hang Pham TT, So S. Causes and trends in liver disease and hepatocellular carcinoma among men and women who received liver transplants in the U.S., 2010–2019. PLoS One 2020;15 e023939310.1371/journal.pone.0239393.

[14] Riera R, Bagattini AM, Pacheco RL, Pachito DV, Roitberg F, Ilbawi A. Delays and Disruptions in Cancer Health Care Due to COVID-19 Pandemic: Systematic Review. JCO Glob Oncol 2021;7:311–23. doi:10.1200/GO.20.00639.

[15] Chandrasinghehtha W, Leeahavanichkul A. Acute kidney injury spectrum in patients with chronic liver disease: Where do we stand? World J Gastroenterol 2019;25:3684–703. doi:10.3748/wjg.v25.i28.3684.

[16] Agopian V, Verna E, Goldberg D. Changes in Liver Transplant Center Practice in Response to Coronavirus Disease 2019: Unmasking Dramatic Center-Level Variability. Liver Transpl 2020;26:1052–5. doi:10.1002/lt.25789.

[17] Sandal S, Boyarsky BJ, Massie A, Chiang TP, Segev DL, Cantarovich M. Immunosuppression practices during the COVID-19 pandemic: A multinational survey study of transplant programs. Clin Transplant 2021;35 e1437610.1111/tid.13492.

[18] Dhand A, Bodin R, Wolf DC, Schluger A, Nabors C, Nog R, Dillo T, et al. Successful liver transplantation in a patient recovered from COVID-19. Transpl Infect Dis 2021;23:e13492.

[19] Patel SY, Mehrorat A, Huskamp HA, Uscher-Pines L, Ganguli I, Barnett ML. Trends in Outpatient Care Delivery and Telemedicine During the COVID-19 Pandemic in the US. JAMA Intern Med 2021;181:388–91. doi:10.1001/jamainternmed.2020.5928.