Clinical Transplantation

WILEY

Clinical TRANSPLANTATION
The Journal of Clinical and Translational Research

ORIGINAL ARTICLE OPEN ACCESS

Trends, Clinical Characteristics, and Outcomes of Percutaneous Coronary Intervention in Liver Transplant Recipients

Song Peng Ang MD[1] | Jia Ee Chia MD[2] | Jose Iglesias DO, FASN[1] | Chayakrit Krittanawong MD, FACC[3]

[1]Department of Medicine, Rutgers Health/Community Medical Center, Toms River, New Jersey, USA | [2]Department of Medicine, Texas Tech University Health Science Center, El Paso, Texas, USA | [3]HumanX, Delaware, Delaware, USA

Correspondence: Song Peng Ang (spa45@rutgers.edu)

Received: 5 February 2025 | **Revised:** 12 April 2025 | **Accepted:** 26 April 2025

Funding: The authors received no specific funding for this work.

Keywords: cardiovascular outcomes | coronary artery disease | coronary intervention | immunosuppressant | liver transplant

ABSTRACT

Background: Coronary artery disease (CAD) poses a significant challenge for liver transplant recipients (LTRs) who face higher cardiovascular risks due to immunosuppressive therapies and metabolic changes. While extensive research has focused on CAD management in patients awaiting liver transplantation, data on the outcomes of percutaneous coronary intervention (PCI) in the post-transplant population remain limited.

Methods: This retrospective cohort study used the National Inpatient Sample database (2016–2021) to evaluate PCI hospitalizations involving LTR and non-transplant patients. Propensity score matching (1:3) was applied to balance the covariates between the LTRs and non-transplant patients. The primary outcome was in-hospital mortality.

Results: Among the 2 681 545 PCI hospitalizations, LTRs accounted for 0.1% ($n = 2675$). LTRs were more likely to have diabetes (60.56% vs. 41.36%) and chronic kidney disease (60.93% vs. 21.06%) but less likely to have hyperlipidemia (58.32% vs. 72.65%; all $p < 0.001$). The crude rates of AKI (32.34% vs. 16.07%; $p < 0.001$) and blood transfusion (5.61% vs. 2.76%; $p = 0.0001$) were higher in the LTRs. After matching, the LTRs were associated with lower odds of in-hospital mortality (OR, 0.55; 95% CI, 0.30–1.00; $p = 0.05$) and cardiogenic shock (OR, 0.46; 95% CI, 0.29–0.74; $p = 0.001$). PCI hospitalizations among LTRs increased over time, peaking in 2019 (116.6/100 000).

Conclusion: Despite higher comorbidities and complication rates, LTRs undergoing PCI exhibited lower in-hospital mortality than non-transplant patients, likely reflecting survivor bias, rigorous pre- and post-transplant care, and specialized management. These preliminary findings highlight the need for further studies with detailed clinical data to validate the current findings.

1 | Introduction

Coronary artery disease (CAD) presents a health challenge for liver transplant recipients (LTR) and significantly affects both morbidity and mortality in this growing population [1]. With advances in liver transplantation and immunosuppressive therapies, LTRs are living longer, but they now face increased risks of cardiovascular disease, including CAD [2, 3]. Although there has been extensive research on CAD management in patients awaiting liver transplantation, primarily to optimize perioperative safety, data on the outcomes of coronary revascularization in the post-liver transplant population remain limited

[4]. This knowledge gap complicates the development of effective evidence-based management strategies for CAD among liver transplant survivors.

Existing studies have predominantly focused on screening and treating CAD before liver transplantation, to minimize immediate cardiovascular risks during the procedure [4, 5]. However, the post-transplant period introduces unique and evolving challenges for LT recipients. Chronic immunosuppressive therapy, particularly with medications such as calcineurin inhibitors and corticosteroids, is essential for preventing graft rejection and has been associated with increased cardiovascular risk, including hypertension, dyslipidemia, diabetes, and renal dysfunction [6–9]. These factors may accelerate atherosclerosis and, consequently, increase the risk of coronary events [10]. Furthermore, the complex metabolic changes following liver transplantation add an additional layer of cardiovascular risk, potentially demanding novel approaches to CAD management that go beyond traditional strategies [11].

The lack of robust evidence on revascularization outcomes in post-liver transplant patients emphasizes the need for dedicated research to bridge the knowledge gap to enhance patient care. This study aimed to evaluate the current trends and clinical outcomes of percutaneous coronary intervention (PCI) in LTR.

2 | Methods

2.1 | Study Design and Data Source

This retrospective cohort study used the National Inpatient Sample (NIS) database from 2016 to 2021 [12]. The NIS is the largest publicly available database of all-payer inpatient hospitalizations in the United States. Annually, it provides data on approximately seven million hospitalizations, representing a 20% stratified sample of discharges from the United States community hospitals, excluding rehabilitation and long-term acute care facilities. All research was conducted following the ethical principles outlined in the Declarations of Helsinki and Istanbul. Institutional Review Board approval was waived as this study utilized publicly available, deidentified data.

2.2 | Patient Selection and Identification

The study included adult patients (aged ≥ 18 years) who underwent PCI. LTRs were identified as individuals with a documented history of liver transplantation based on ICD-10-CM code Z94.4. Patients without a history of liver transplantation served as controls. Hospitalizations without demographic or clinical information, including age, sex, race, and in-hospital mortality, were excluded from this study. Patients were also excluded if they had a diagnosis of chronic liver disease, underwent coronary artery bypass graft (CABG) surgery or liver transplantation during the index admission, or had a history of other solid organ transplants, including the lung, heart, or kidney.

2.3 | Outcomes

The primary outcome was in-hospital mortality, while secondary outcomes included in-hospital events, including cardiogenic shock, cardiac arrest, acute kidney injury (AKI), bleeding complications, requirement for blood transfusion, length of hospital stay, and cost of hospitalization.

2.4 | Statistical Analysis

Survey-weighted methods were applied to generate nationally representative estimates in addition to accounting for the complex survey design. Continuous variables were summarized using survey-weighted means with standard deviations (SD), and categorical variables were presented as survey-weighted frequencies with corresponding percentages. Univariate comparisons between the liver transplant and non-LT cohorts were conducted using survey-weighted chi-square tests for categorical variables and survey-weighted linear regression for continuous measures.

To address potential baseline imbalances and confounding factors, propensity score matching was performed using a nearest-neighbor algorithm with a 1:3 ratio of liver transplant to non-liver transplant patients. Propensity scores were estimated using a logistic regression model incorporating all covariates listed in Table 1. Matching was performed using a nearest-neighbor algorithm without replacement in a 1:3 ratio with the closest propensity scores within a defined caliper width of 0.2 standard deviations of the logit of the propensity score. The balance of covariates between the matched groups was evaluated using standardized mean differences (SMDs), with an SMD of less than 0.1 indicating adequate balance. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to quantify effect sizes. Stratified analyses were conducted to assess potential effect modification for the primary outcome across subgroups defined by age, sex, sociodemographic characteristics, and the presence of ST-elevation myocardial infarction (STEMI). A two-tailed p value < 0.05 was considered statistically significant for all analyses. Statistical computations were performed using the STATA software (version 18.0; StataCorp LLC, College Station, TX, USA).

3 | Results

In this contemporary analysis of 2 681 545 PCI hospitalizations over 6 years, LTR constituted 0.1% ($n = 2675$) of the cohort (Table 1). The mean age did not differ significantly between LTR and non-transplant individuals (66.03 ± 8.08 years vs. 65.61 ± 12.53 years; $p = 0.223$). There was a lower proportion of female patients in the LTR group than in the nontransplant group (21.12% vs. 33.31%; $p < 0.001$).

Significant racial disparities were observed between the two groups ($p < 0.001$). A higher proportion of LTR were non-Hispanic White compared to non-transplant individuals (80.56% vs. 75.10%), while non-Hispanic Black individuals were less represented among LTR (4.11% vs. 9.81%). Hospital characteristics also differed significantly between the groups. LTR was more likely to receive care in large hospitals (60.75% vs.

TABLE 1 | Baseline characteristics of patients with and without a history of liver transplant.

Variables	No history of liver transplant ($n = 2\,678\,870$)	History of liver transplant ($n = 2675$)	Total ($n = 2\,681\,545$)	p value
Age	65.61 ± 12.53	66.03 ± 8.08	65.61 ± 12.52	0.223
Female	892 360 (33.31)	565 (21.12)	892 925 (33.30)	< 0.001
Race				< 0.001
White	2 011 890 (75.10)	2155 (80.56)	2 014 045 (75.11)	
Black	262 885 (9.81)	110 (4.11)	262 995 (9.81)	
Hispanic	222 425 (8.30)	280 (10.47)	222 705 (8.31)	
Asian or Pacific Islander	75 050 (2.80)	30 (1.12)	75 080 (2.80)	
Native American	15 005 (0.56)	40 (1.50)	15 045 (0.56)	
Other	91 615 (3.42)	60 (2.24)	91 675 (3.42)	
Hospital bed size				0.0183
Small	420 330 (15.69)	330 (12.34)	420 660 (15.69)	
Medium	788 060 (29.42)	720 (26.92)	788 780 (29.42)	
Large	1 470 481 (54.89)	1625 (60.75)	1 472 106 (54.90)	
Hospital teaching status				< 0.001
Rural	148 940 (5.56)	105 (3.93)	149 045 (5.56)	
Urban non-teaching	537 665 (20.07)	330 (12.34)	537 995 (20.06)	
Urban teaching	1 992 264 (74.37)	2240 (83.74)	1 994 504 (74.38)	
Admission				
Elective	257 365 (9.61)	280 (10.47)	257 645 (9.61)	0.5027
Median household income, $				0.0031
1–28 999	794 845 (29.67)	595 (22.24)	795 440 (29.66)	
29 000–35 999	728 850 (27.21)	795 (29.72)	729 645 (27.21)	
36 000–46 999	640 535 (23.91)	720 (26.92)	641 255 (23.91)	
47 000+	514 640 (19.21)	565 (21.12)	515 205 (19.21)	
Hospital region				0.168
Northeast	468 995 (17.51)	525 (19.63)	469 520 (17.51)	
Midwest	617 730 (23.06)	600 (22.43)	618 330 (23.06)	
South	1 119 385 (41.79)	1170 (43.74)	1 120 555 (41.79)	
West	472 759 (17.65)	380 (14.21)	473 139 (17.64)	
Comorbidities				
Congestive heart failure	1 037 480 (38.73)	1150 (42.99)	1 038 630 (38.73)	0.0492
Atrial fibrillation	406 975 (15.19)	465 (17.38)	407 440 (15.19)	0.1764
Valvular heart diseases	373 005 (13.92)	520 (19.44)	373 525 (13.93)	0.0004
Peripheral vascular disease	313 455 (11.70)	335 (12.52)	313 790 (11.70)	0.5569
Hypertension	2 199 040 (82.09)	2320 (86.73)	2 201 360 (82.09)	0.0052
Diabetes	1 107 900 (41.36)	1620 (60.56)	1 109 520 (41.38)	< 0.001
Smoking	660 795 (24.67)	365 (13.64)	661 160 (24.66)	< 0.001
Prior MI	484 230 (18.08)	440 (16.45)	484 670 (18.07)	0.3571
Prior coronary revascularization	293 015 (10.94)	325 (12.15)	293 015 (10.93)	0.3567
Hyperlipidemia	1 946 145 (72.65)	1560 (58.32)	1 947 705 (72.63)	< 0.001
Chronic lung disease	537 185 (20.05)	400 (14.95)	537 585 (20.05)	0.0037
Hypothyroidism	309 365 (11.55)	420 (15.70)	309 785 (11.55)	0.0024

(Continues)

TABLE 1 | (Continued)

Variables	No history of liver transplant ($n = 2\,678\,870$)	History of liver transplant ($n = 2675$)	Total ($n = 2\,681\,545$)	p value
CKD	564 105 (21.06)	1630 (60.93)	565 735 (21.10)	< 0.001
Coagulopathy	123 490 (4.61)	325 (12.15)	123 815 (4.62)	< 0.001
Obesity	583 405 (21.78)	435 (16.26)	583 840 (21.77)	0.0018
Anemia	83 320 (3.11)	100 (3.74)	83 420 (3.11)	0.4013
Alcohol abuse	79 215 (2.96)	180 (6.73)	79 395 (2.96)	< 0.001
Elixhauser comorbidities	3.68 ± 2.18	5.54 ± 2.22	3.68 ± 2.18	< 0.001

Abbreviations: CKD, chronic kidney disease; MI, myocardial infarction.

54.89%; $p = 0.018$) and urban teaching hospitals (83.74% vs. 74.37%; $p < 0.001$), whereas rural and urban non-teaching hospitals accounted for a smaller proportion of admissions among LTR. The rate of elective PCI procedures was similar between groups (10.47% vs. 9.61%; $p = 0.503$). Socioeconomic indicators highlighted modest differences, with LTR less frequently residing in the lowest income quartile (22.24% vs. 29.67%; $p = 0.0031$).

Comorbid conditions varied considerably between the groups. LTR exhibited significantly higher rates of diabetes (60.56% vs. 41.36%; $p < 0.001$), chronic kidney disease (60.93% vs. 21.06%; $p < 0.001$), coagulopathy (12.15% vs. 4.61%; $p < 0.001$), and alcohol abuse (6.73% vs. 2.96%; $p < 0.001$). In contrast, hyperlipidemia and chronic lung disease were less prevalent in LTR than in non-transplant individuals (58.32% vs. 72.65%; $p < 0.001$, and 14.95% vs. 20.05%; $p = 0.0037$, respectively).

3.1 | Unadjusted In-Hospital Events/Outcomes

The crude in-hospital mortality rate did not differ significantly between the two groups (2.43% for LTR vs. 3.00% for non-transplant individuals; $p = 0.4364$) (Table 2). The crude rates of cardiogenic shock and cardiac arrest were also comparable, with a trend toward lower cardiogenic shock in the LTR group (3.93% vs. 5.82%; $p = 0.0587$) and similar rates of cardiac arrest (2.62% vs. 3.18%; $p = 0.4566$). However, the LTR group exhibited significantly higher crude rates of AKI (32.34% vs. 16.07%; $p < 0.001$) and blood transfusion requirements (5.61% vs. 2.76%; $p = 0.0001$). Bleeding complications occurred at similar rates in the two groups (5.98% vs. 4.98%; $p = 0.2823$). Hospital resource utilization was notably greater in LTR, reflected in longer mean lengths of stay (5.44 ± 6.97 days vs. 4.00 ± 5.21 days; $p < 0.001$) and higher mean hospitalization costs ($32 377.28 ± $32 123.86 vs. $27 369.56 ± $24 752.04; $p < 0.001$).

3.2 | In-Hospital Events/Outcomes After Propensity-Score Matching

After propensity score matching in a 1:3 ratio, we analyzed 2675 LTRs and 8025 non-transplant patients (Figure 1). The analysis revealed that liver transplant status was associated with a reduction in the odds of in-hospital mortality (OR, 0.55; 95% CI, 0.30–1.00; $p = 0.05$), but narrowly missed the statistical significance threshold. Similarly, the incidence of cardiogenic shock was significantly lower among LTRs than among their non-transplant counterparts (OR, 0.46; 95% CI, 0.29–0.74; $p = 0.001$). However, no significant differences were observed in the odds of other adverse events, including cardiac arrest (OR, 0.69; 95% CI, 0.38–1.25; $p = 0.221$); AKI (OR, 1.14; 95% CI, 0.92–1.41; $p = 0.224$); bleeding complications (OR, 0.86; 95% CI, 0.57–1.29; $p = 0.455$); and the need for blood transfusion (OR, 0.94; 95% CI, 0.61–1.46; $p = 0.796$).

3.3 | Subgroup Analysis of In-Hospital Mortality Between LTR and Non-Transplant Cohort

In this subgroup analysis, age, sex, elective admission status, and income levels did not significantly affect outcomes between the two groups (Table S1). Rural hospitals had higher odds of adverse outcomes than urban teaching hospitals (OR 4.31, 95% CI: 1.00–18.57, $p = 0.05$), while hospital bed size showed no significant differences. Additionally, there is no significant difference in the risk of in-hospital mortality when stratified by the presence of STEMI.

3.4 | Trend of PCI Hospitalization Involving LTR

From 2016 to 2021, there was a notable upward trend in the proportion of LTR undergoing PCI hospitalization (Figure 1). In 2016, the rate was 78.3 per 100 000 PCI hospitalizations, which progressively increased to 84.5 in 2017 and 103.2 in 2018. The trend peaked in 2019 at 116.6 per 100 000 individuals. Following this peak, there was a slight decline to 108.1 in 2020 and 107.9 in 2021.

3.5 | Trends in AKI and Composite of Bleeding or Need for Blood Transfusion

The incidence of AKI among LTR undergoing PCI showed year-to-year variability (Figure 2). In 2016, the rate was 30.0%, which increased to 35.1% in 2017. This was followed by a decline to 29.5% in 2018, a slight increase to 32.4% in 2019, and a return to the 2016 baseline of 30.0% in 2020. By 2021, the AKI rate for LTR increased again to 37.0%, representing the highest rate observed during the 6 years. Among non-transplant patients, the AKI rate exhibited a more consistent upward trend. Starting at 13.9% in 2016, the rate has increased incrementally yearly, reaching 18.1%

TABLE 2 | In-hospital management, events, and outcomes.

Variables	Non-transplant ($n = 2\,678\,870$)	Liver transplant recipients ($n = 2675$)	p value
AMI	1 889 710 (70.54)	1670 (62.43)	< 0.001
STEMI	802 975 (29.97)	585 (21.87)	< 0.001
IVUS	249 625 (9.32)	305 (11.40)	0.1064
FFR	121 905 (4.55)	90 (3.36)	0.1848
CTO	178 935 (6.68)	145 (5.42)	0.2414
BMS	145 675 (5.44)	165 (6.17)	0.4492
DES	2 338 600 (87.30)	2290 (85.61)	0.2322
Use of assist device (LVAD, IABP)	145 985 (5.45)	165 (6.17)	0.4686
Events/Outcomes			
In-hospital Mortality	80 430 (3.00)	65 (2.43)	0.4364
Cardiogenic shock	155 810 (5.82)	105 (3.93)	0.0587
Cardiac arrest	85 230 (3.18)	70 (2.62)	0.4566
Acute kidney injury	430 590 (16.07)	865 (32.34)	< 0.001
Bleeding complications	133 500 (4.98)	160 (5.98)	0.2823
Blood transfusion	73 905 (2.76)	150 (5.61)	0.0001
Length of stay, days	4.00 ± 5.21	5.44 ± 6.97	< 0.001
Cost of hospitalizations, USD	27 369.56 ± 24 752.04	32 377.28 ± 32 123.86	< 0.001

Abbreviations: AMI, acute myocardial infarction; BMS, bale-metal stent; CTO, chronic total occlusion; DES, drug-eluting stent; FFR, fractional flow reserve; IABP, intra-aortic balloon pump; IVUS, intravascular ultrasound; LVAD, left ventricular assist device; STEMI, ST-elevation myocardial infarction.

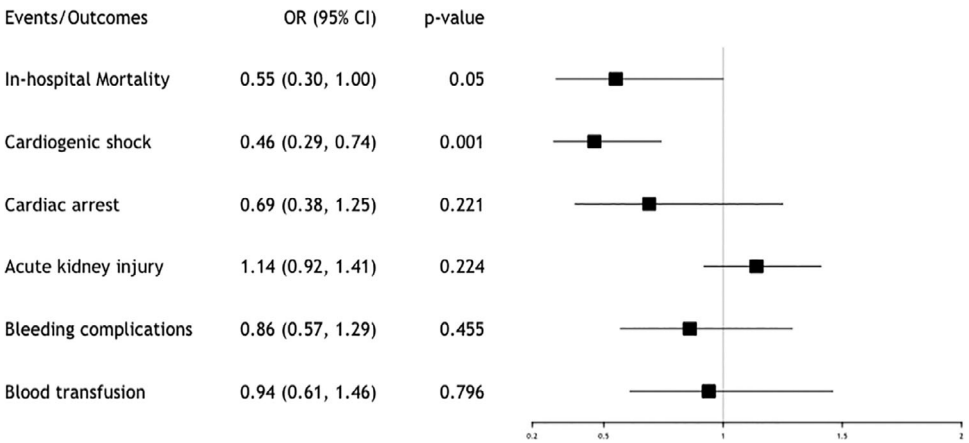

FIGURE 1 | Forest plot of in-hospital events/outcomes after propensity-score matching.

by 2021. Although the rates of AKI were consistently higher in LTR patients than in non-transplant patients, the gradual rise in AKI among the non-transplant cohort contrasts with the fluctuating rates observed in the LTR group.

The incidence of bleeding and transfusion among LTR showed notable variability over the study period (Figures 3 and 4). In 2016, the rate was 11.4%, sharply declining to 6.5% in 2017 and further to 5.3% in 2018. However, a substantial increase occurred in 2019, with a rate increasing to 12.6%, followed by a peak of 15.6% in 2020. By 2021, the rate had decreased to 5.4%, the lowest observed during this period. For non-transplant patients, composite bleeding or transfusion rates remained stable, showing a slight upward trend. Starting at 6.0% in 2016, the rate was largely unchanged, fluctuated slightly, and reached 6.9% in 2021.

4 | Discussion

We identified several important findings in this extensive, contemporary analysis of over 2.6 million PCI hospitalizations. First, LTR comprised a small proportion of patients undergoing PCI (0.1%). Second, after propensity score matching, LTRs were associated with lower odds of in-hospital mortality and cardiogenic shock despite similar rates of other complications, including AKI and bleeding. Third, hospitalization resource utilization was

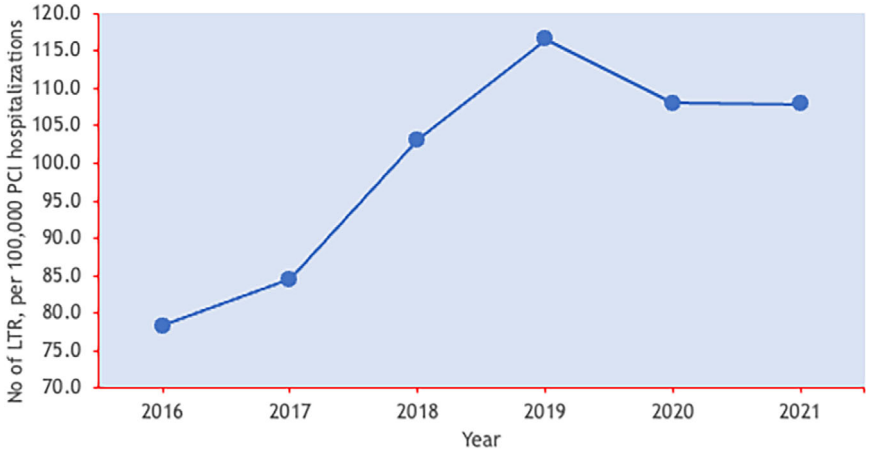

FIGURE 2 | Temporal trend of liver transplant recipients (LTR) undergoing PCI.

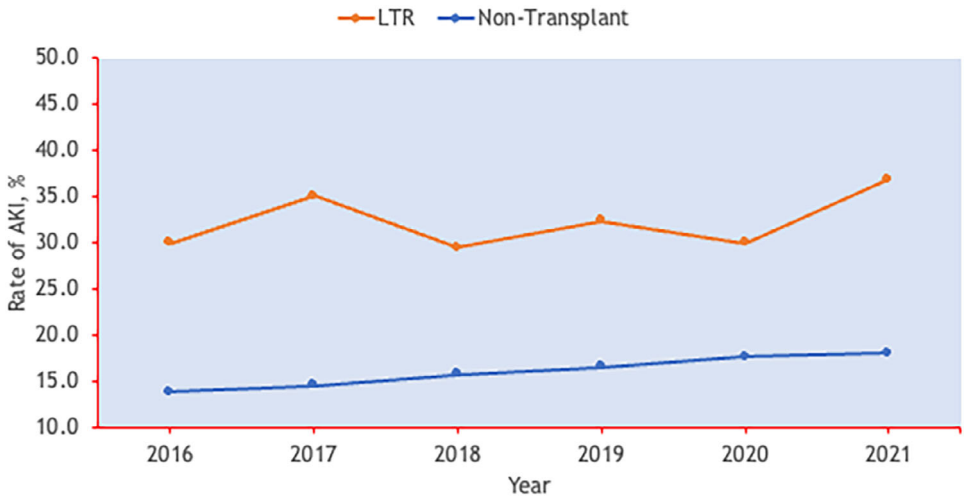

FIGURE 3 | Temporal trend of acute kidney injury (AKI), by transplant status.

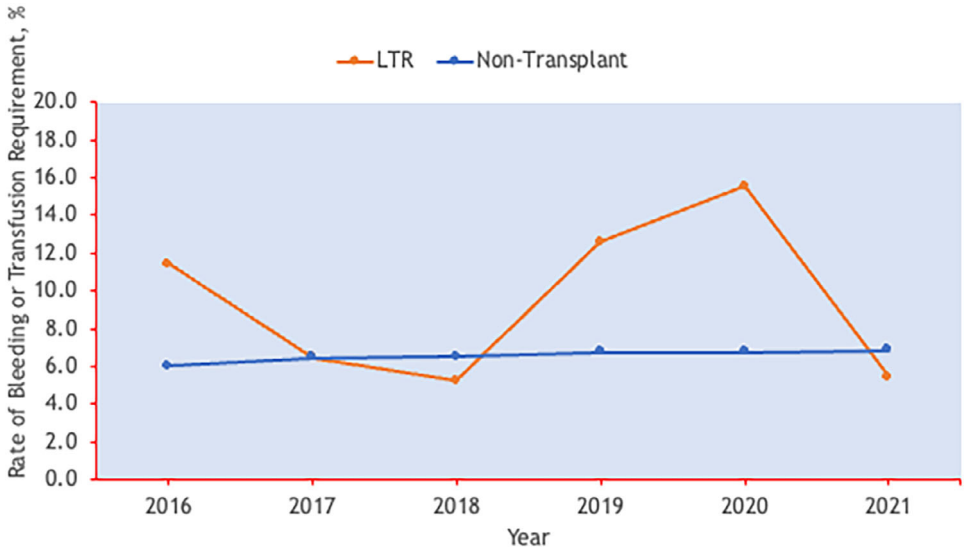

FIGURE 4 | Temporal trend of bleeding or transfusion requirement by transplant status.

higher among LTRs, as reflected by longer lengths of stay and higher costs of hospitalizations. Finally, we observed an upward trend in the proportion of LTRs who underwent PCI over the 6-year study period.

Shah et al. predated our study by retrospectively comparing a cohort of post-liver transplant patients with non-transplant patients using the same database but from an earlier study period from 2010 to 2014 [13]. They analyzed approximately 8 million PCI hospitalizations, of which 0.04% ($n = 4080$) had a history of liver transplantation. At baseline, the LTR group was younger but had a higher proportion of CV comorbidities, including hypertension, diabetes, and valvular heart disease. In the propensity score-matched analysis, the LTR group was found to have a significantly lower risk of in-hospital mortality than the non-transplant group. The LTR group had a higher risk of bleeding complications (5.1% vs. 6.2%, $p = 0.067$), but this difference was not statistically significant. Despite having a significantly higher risk of AKI in the LTR group, there was no significant difference in the risk of AKI requiring dialysis between the two cohorts. Our study extended the study period to a contemporary era and included the COVID-19 period. Overall, the study findings were consistent with prior studies and provided a modern perspective on the patients who underwent liver transplants.

Several explanations exist for the lower mortality rate observed in the LTR group than in the non-transplant group. First, survivorship bias was a key factor [14]. Patients who undergo liver transplantation represent a rigorously selected population, as only those with sufficient coronary and cardiac reserves are deemed eligible for this highly invasive procedure [5]. Most LTRs undergo comprehensive preoperative cardiac evaluations, including stress testing, coronary angiography, and PCI. These interventions are both diagnostic and therapeutic and address significant coronary stenosis before transplantation. By managing critical lesions earlier, these procedures may reduce the risk of ischemic events and procedural complications, contributing to the observed survival advantage during post-transplant PCI [15]. Additionally, post-transplant PCI is often performed in a physiologically optimized environment. Transplant recipients benefit from tailored cardiovascular management, including antiplatelet agents, statins, and aggressive blood pressure control [2]. These factors likely improve outcomes in this group despite their higher baseline risk than non-transplant patients.

Furthermore, LTRs may exhibit fewer competing risks, such as metastatic malignancies or severe comorbidities, which might otherwise preclude them from undergoing liver transplantation [16]. Close post-transplant monitoring further supports this survival advantage [2]. Routine follow-ups and vigilant cardiac surveillance facilitate early detection and timely management of cardiovascular issues [2, 17]. While necessary to prevent graft rejection, immunosuppressive regimens may also modulate inflammatory responses, potentially reducing myocardial injury and systemic inflammation during and after PCI procedures [18, 19].

Finally, urban–rural disparities in care may play a role. Our study found that LTRs are more commonly treated in urban settings, which are often equipped with advanced resources and specialized expertise [20]. Subgroup analysis revealed that patients treated in rural settings had a fourfold higher risk of in-hospital mortality than their urban counterparts, although this finding marginally missed statistical significance. These observations underscore the importance of access to high-quality care to improve outcomes for this unique patient population.

4.1 | Limitations

Our study had several significant limitations. First, the use of the NIS database inherently limits the granularity of available data. Clinical details, such as angiographic findings, the extent and severity of coronary artery disease, and angiographic or lesion characteristics, were unavailable. Second, given the constraints of the database, we could not assess the temporal relationships or causality between interventions and outcomes. Third, our analysis focused on in-hospital mortality and in-hospital events without long-term consequences, such as major adverse cardiovascular events (MACE) or patient survival after discharge. Fourth, the reliance on administrative coding in the NIS database introduces the potential for misclassification errors, including identifying liver transplant status, complications, or comorbidities. Finally, the outcomes were not adjusted for chronic medication use, and the lack of detailed information on immunosuppressive regimens, adjunctive medical therapies, and medication compliance further limited the scope of our findings. Given the increasing number of LTRs, as evident in our study, future studies with longitudinal follow-up, medication use, and intervention timing are warranted to optimize the cardiovascular care of LTRs.

5 | Conclusion

In this contemporary analysis of PCI hospitalizations, while LTRs experienced consistently higher crude rates of AKI and bleeding/transfusion events than non-transplant patients, these events were attenuated in propensity score-matched analysis, likely explained by confounders in the LTR group. However, LTR demonstrated a paradoxical, lower in-hospital mortality rate than the non-transplant group. The upward trend in PCI hospitalization among LTRs may reflect improved overall survival and emphasize the need for tailored cardiovascular management strategies in this expanding cohort. Our findings suggest that the lower in-hospital mortality observed in LTRs may reflect survivor bias, enhanced post-transplant monitoring, individualized cardiovascular care, and treatment at specialized urban centers. Given the limitations of administrative databases in capturing granular clinical details, future studies should focus on integrating detailed angiographic data, the timing of interventions, and longitudinal outcomes. Such analyses are essential to provide additional insights into the validity of the current study and improve our knowledge and care of this high-risk population.

Author Contributions

Song Peng Ang: conceptualization, methodology, investigation, writing–original draft preparation, writing–reviewing and editing. **Jia Ee Chia**: data acquisition, analysis, interpretation, visualization, writing–original draft preparation. **Jose Iglesias**: analysis, interpretation, writing–original

draft preparation, writing–reviewing and editing. **Chayakrit Krittanawong**: writing–reviewing and editing, validation, project administration, supervision.

Acknowledgments

The authors have nothing to report.

Disclosure

The authors have nothing to report.

Ethics Statement

This study involved the analysis of a database with de-identified data. Hence, ethical approval was not required for this study.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data supporting this study were extracted from the National Inpatient Sample and are available upon application to the HCUP database. Restrictions were applied as these were used under the license for this study.

References

1. W. D. Carey, J. A. Dumot, R. R. Pimentel, et al., "The Prevalence of Coronary Artery Disease in Liver Transplant Candidates Over Age 50," *Transplantation* 59, no. 6 (1995): 859–864.

2. M. Izzy, B. E. Fortune, M. Serper, et al., "Management of Cardiac Diseases in Liver Transplant Recipients: Comprehensive Review and Multidisciplinary Practice-Based Recommendations," *American Journal of Transplantation* 22, no. 12 (2022): 2740–2758.

3. M. R. Lucey, N. Terrault, L. Ojo, et al., "Long-Term Management of the Successful Adult Liver Transplant: 2012 Practice Guideline by the American Association for the Study of Liver Diseases and the American Society of Transplantation," *Liver Transplantation* 19, no. 1 (2013): 3–26.

4. S. P. Ang, J. E. Chia, J. Iglesias, M. H. Usman, and C. Krittanawong, "Coronary Intervention Outcomes in Patients With Liver Cirrhosis," *Current Cardiology Reports* 27, no. 1 (2025): 2, https://link.springer.com/article/10.1007/s11886-024-02163-x.

5. X. S. Cheng, L. B. VanWagner, S. P. Costa, et al., "Emerging Evidence on Coronary Heart Disease Screening in Kidney and Liver Transplantation Candidates: A Scientific Statement From the American Heart Association: Endorsed by the American Society of Transplantation," *Circulation* 146, no. 21 (2022): e299–e324.

6. A. Elezaby, R. Dexheimer, and K. Sallam, "Cardiovascular Effects of Immunosuppression Agents," *Frontiers in Cardiovascular Medicine* 9 (2022): 981838, https://www.frontiersin.org/journals/cardiovascular-medicine/articles/10.3389/fcvm.2022.981838/full.

7. J. M. Rabkin, C. L. Corless, H. R. Rosen, and A. J. Olyaei, "Immunosuppression Impact on Long-Term Cardiovascular Complications After Liver Transplantation," *American Journal of Surgery* 183, no. 5 (2002): 595–599.

8. L. W. Miller, "Cardiovascular Toxicities of Immunosuppressive Agents," *American Journal of Transplantation* 2, no. 9 (2002): 807–818.

9. S. P. Ang, J. E. Chia, V. Jaiswal, et al., "Vascular Complications and Outcomes Following Transcatheter Aortic Valve Replacement in Patients on Chronic Steroid Therapy: A Meta-analysis," *International Journal of Surgery* 110, no. 4 (2024): 2421–2429.

10. S. P. Ang, J. E. Chia, K. Misra, et al., "Autoimmune Rheumatic Diseases and Outcomes Following Percutaneous Coronary Intervention: A Systematic Review and Meta-Analysis," *Angiology* (2024): 33197241255167. Published online May 21, 2024, https://doi.org/10.1177/00033197241255167.

11. C. Becchetti, M. Dirchwolf, V. Banz, and J. F. Dufour, "Medical Management of Metabolic and Cardiovascular Complications After Liver Transplantation," *World Journal of Gastroenterology* 26, no. 18 (2020): 2138–2154.

12. HCUP National Inpatient Sample (NIS), "Healthcare Cost and Utilization Project (HCUP)," Agency for Healthcare Research and Quality Rockville MD, 2016-2021), www.hcup-us.ahrq.gov/nisoverview.jsp.

13. H. Shah, G. Ramineni, R. Varghese, et al., "Outcomes of Percutaneous Coronary Interventions in Patients With Liver Transplant," *Catheterization and Cardiovascular Interventions* 96, no. 6 (2020): E576–E584.

14. D. M. Elston, "Survivorship Bias," *Journal of the American Academy of Dermatology* Published online June 18 2021, https://doi.org/10.1016/j.jaad.2021.06.845.

15. I. Kutkut, R. J. Rachwan, L. R. Timsina, et al., "Pre-Liver Transplant Cardiac Catheterization Is Associated with Low Rate of Myocardial Infarction and Cardiac Mortality," *Hepatology* 72, no. 1 (2020): 240–256.

16. P. Martin, A. DiMartini, S. Feng, R. Brown Jr., and M. Fallon, "Evaluation for Liver Transplantation in Adults: 2013 Practice Guideline by the American Association for the Study of Liver Diseases and the American Society of Transplantation," *Hepatology* 59, no. 3 (2014): 1144–1165.

17. L. B. VanWagner, E. Gordon, L. Adamski, et al., "Liver Transplant Recipient, Caregiver, and Provider Perceptions of Cardiovascular Disease and Related Risk Factors after Transplant," *Liver Transplantation* 27, no. 5 (2021): 668–683.

18. P. H. Sung, W. C. Huang, T. H. Chao, et al., "Intra-Coronary Administration of Tacrolimus Improves Myocardial Perfusion and Left Ventricular Function in Patients With ST-Segment Elevation Myocardial Infarction (COAT-STEMI) Undergoing Primary Percutaneous Coronary Intervention," *Acta Cardiologica Sinica* 37, no. 3 (2021): 239–253.

19. F. Ribichini, F. Tomai, V. Ferrero, et al., "Immunosuppressive Oral Prednisone After Percutaneous Interventions in Patients With Multi-Vessel Coronary Artery Disease. The IMPRESS-2/MVD Study," *EuroIntervention* 1, no. 2 (2005): 173–180.

20. N. S. Khurmi, Y. H. Chang, D. Eric Steidley, et al., "Hospitalizations for Cardiovascular Disease After Liver Transplantation in the United States," *Liver Transplantation* 24, no. 10 (2018): 1398–1410.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.