ORIGINAL ARTICLE

Liver transplant program outcomes at a Colombian center: 14 years of experience

Resultados del programa de trasplante de hígado en un centro colombiano: 14 años de experiencia

Maricel Licht-Ardila[1], Giseth A. Mosquera-Velasquez[2], Angie V. Abril-Lopera[2], Alexandra Hurtado-Ortiz[1], Luis A. Olarte-Licht[2], Santiago Flórez-Suárez[1], Lizeth C. Padilla-Padilla[3], Elizabeth C. David-Gonzalez[3], Joel Duarte-Yepes[3], Alejandra Mendoza-Monsalve[1], Skarlet M. Vásquez[2], Gabriel J. Arenas-Peña[3], Mauricio Vanegas-Ballesteros[3], and Cristian E. Tarazona-Leon[3]*

[1]Department of Epidemiology, Fundatción Cardiovascular de Colombia; [2]Department of Health Sciences, Universidad Autónoma de Bucaramanga (UNAB); [3]Department of Hepatic Transplantation, Fundatción Cardiovascular de Colombia. Santander, Colombia

Abstract

Objectives: *The objective of the study was to analyze outcomes of a liver transplant program over 14 years and evaluate associations between patient characteristics, surgical factors, complications, and mortality.* **Methods:** *A retrospective cohort study was conducted at a transplant center, including patients from 2011 to 2025. Descriptive statistics, X^2, Mann–Whitney U tests, and multivariate logistic regression were used to identify mortality predictors. Kaplan-Meier survival analysis was also performed.* **Results:** *The study included 109 liver transplant recipients. Rejection rates were higher among deceased patients (30.3% vs. 13.2%, p = 0.034). One-year survival improved from 63.3% (2011-2014) to 89.1% (2023-2025), with 100% rejection-free survival in the most recent cohort. Complications like multi-organ failure, bronchopneumonia, acute renal failure, ventilatory failure with coma, and leukoencephalopathy significantly increased mortality risk (odds ratio 4.27, p = 0.002).* **Conclusions:** *One-year survival has improved, with reduced rejection rates reflecting better post-transplant care. However, complications remain a major mortality risk. Shorter ischemia times indicate optimized surgical and logistical procedures.*

Keywords: *Liver transplantation. Mortality. Survival. Complications. Graft rejection. Tissue donors.*

Resumen

Objetivos: *Analizar los resultados de un programa de trasplante hepático durante 14 años y evaluar la relación entre las características del paciente, los factores quirúrgicos, las complicaciones y la mortalidad.* **Métodos:** *Estudio de cohorte retrospectivo en un centro de trasplantes, incluyendo pacientes entre 2011 y 2025. Se usaron estadísticas descriptivas con pruebas χ^2 y U de Mann-Whitney para identificar predictores de mortalidad. Se aplicó análisis de supervivencia de Kaplan-Meier.* **Resultados:** *Se incluyeron 109 receptores. El rechazo fue mayor en los fallecidos (30.3% vs. 13.2%; p = 0.034). La supervivencia al año mejoró del 63.3% (2011-2014) al 89.1% (2023-2025), con un 100% de supervivencia libre de rechazo en la cohorte más reciente. Las complicaciones como falla multiorgánica, bronconeumonía, insuficiencia renal aguda y falla*

***Correspondence:**
Maricel Licht-Ardila
E-mail: mlichtar@gmail.com

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ventilatoria con coma aumentaron el riesgo de mortalidad (OR: 4.27; p = 0.002). **Conclusiones:** *La supervivencia al año ha mejorado y la reducción del rechazo refleja un mejor cuidado postrasplante. Sin embargo, las complicaciones siguen siendo clave en la mortalidad. Los tiempos de isquemia más cortos indican optimización quirúrgica y logística.*

Palabras clave: *Trasplante hepático. Mortalidad. Supervivencia. Complicaciones. Rechazo del injerto. Donantes.*

Introduction

Liver transplantation has become a crucial therapeutic intervention for patients with end-stage liver disease, significantly improving survival rates and quality of life.[1] Worldwide, it is estimated that more than 41,000 people received a liver transplant in 2023, with the American region being the location with the highest number of procedures (around 35%).[2] Since the first transplant in 1963, the procedure has evolved considerably in both surgical techniques and post-operative management.[3] However, it remains a complex intervention with a high risk of complications. At present, patient survival rates at 1, 3, and 5 years are approximately 91.8%, 83.8%, and 76.1%, respectively.[4,5] In Colombia, despite the implementation of this intervention more than four decades ago,[6] challenges persist, including donor availability, access to immunosuppressive therapies, and the management of post-operative complications.[7]

In Colombia, organ donation and transplantation are regulated by a legal framework aimed at ensuring organ availability and improving access to transplants. The legislation follows the principle of presumed consent, meaning individuals are considered donors unless they explicitly choose otherwise. To optimize the donation process, strategies such as awareness campaigns, strengthening the transplant network, and enhancing organ procurement logistics have been implemented.[8] However, liver donation remains a significant challenge due to multiple barriers faced by medical personnel, including insufficient training in brain death certification, difficulties in communicating with families, and limitations in hospital infrastructure. These factors negatively impact donation rates, making it essential to address them from the healthcare team's perspective to enhance access to liver transplantation and improve care for patients on the waiting list.[9]

The long-term success of this intervention largely depends on the appropriate use of immunosuppressive therapies, which prevent graft rejection and improve patient survival. Various immunosuppression protocols combine drugs such as calcineurin inhibitors, antimetabolites, and corticosteroids, each with specific mechanisms of action aimed at modulating the immune response. The selection of an immunosuppressive regimen should be based on multiple factors, including recipient characteristics, rejection risk, and the presence of comorbidities, highlighting the importance of an individualized approach to post-transplant management.[10]

Common complications after liver transplantation include infections, acute graft rejection, renal dysfunction, biliary stenosis, and pulmonary or neurological disorders.[11] Bacterial infections, particularly in the immediate post-operative period, are a major cause of morbidity. Acute rejection usually occurs within the 1st few weeks and requires prompt treatment to preserve graft function. Renal dysfunction is often linked to nephrotoxic immunosuppressants and intraoperative hemodynamic fluctuations. Biliary stenosis, affecting around 13% of recipients, is one of the most significant complications.[12,13] Neurological complications, though less common, range from mild manifestations to potentially life-threatening conditions, reflecting their multifactorial etiology. Given these challenges, this study aims to analyze the key outcomes of a liver transplant program over 14 years in Colombia, identifying the association between patient characteristics, surgical factors, post-operative complications, and mortality after transplantation.

Methods

A retrospective cohort study was conducted at a high-complexity institution, including patients who underwent liver transplantation between May 2011 and March 2025. The study was carried out at a liver transplant center of excellence, supported by a multidisciplinary team of hepatologists, internists, hepatobiliary surgeons, nurses, nutritionists, psychologists, social workers, psychiatrists, anesthesiologists, and nephrologists. Post-transplant follow-up was structured to ensure close monitoring and timely interventions. During the 1st month, patients were evaluated weekly, followed by biweekly assessments if recovery progressed favorably. Subsequently, follow-up visits

were scheduled monthly, then every 3 months, and eventually every 5 months as the post-transplant period lengthened. In cases of liver function abnormalities or immunosuppression imbalances, weekly assessments continued until stabilization was achieved.

Participants

The liver transplantation program includes patients who meet the Milan criteria, which specify that candidates must have either a single liver tumor measuring < 5 cm in diameter or 2-3 tumors, each measuring < 3 cm at the time of diagnosis.[14,15] For this study, all patients enrolled in the liver transplantation program were included in the study. In addition to liver cancer cases that meet these criteria, the program also accommodates patients with other liver diseases requiring transplantation, such as cirrhosis of various etiologies (including viral hepatitis B and C, alcoholic liver disease, metabolic disorders, primary and secondary biliary cirrhosis, and autoimmune hepatitis), polycystic liver disease with associated symptoms and deterioration of quality of life, acute or fulminant hepatitis, and primary biliary cirrhosis in non-cirrhotic patients who experience significant quality of life impairment. Patients < 13 years and those with liver cancer who did not meet Milan criteria were excluded. Participant selection was based on a registry from the liver transplantation center of excellence, following a consecutive selection process to verify eligibility.

Variables

Sociodemographic variables included age (years); sex (male or female); type of social security (contributory, subsidized, particular and other); educational level (primary, secondary, technical, professional, postgraduate and no information); marital status (single, married, separated, widowed, common law union, not disclosed); area of residence (rural or urban); and occupation (homemaker, unemployed, Business person, employee, Independient, others, Disability pensioner).

Clinical variables as personal history, including alcohol consumption (daily consumption: more than seven drinks per week; occasional consumption: less than once per week; weekly consumption: 1-7 drinks per week; does not consume), smoking history (former smoker: quit more than 6 months ago; never smoked; current smoker), diabetes (including whether insulin-dependent), dyslipidemia, obesity, history of hepatitis (A, B, C, or unspecified), heart failure, acute myocardial infarction, and cirrhosis. Family history, including liver cancer, pancreatic cancer, and other types of cancer were also measured.

Variables related to the procedure's characteristics were collected, such as ischemia times (cold and warm), transplant classification (adult or pediatric), donor type (living or deceased), and transplant outcomes such as the need for re-transplantation. Regarding complications, rejection occurrence was assessed and classified as acute, chronic, along with its potential causes, including treatment adherence, administrative factors related to insurance, subtherapeutic drug levels, or other causes. Biliary complications were also analyzed, specifically strictures, bile leaks, and other related issues.

In addition, complications were considered, including the necessity for surgical reintervention. These were categorized based on temporal occurrence, distinguishing between reintervention due to hemorrhage within the initial 48 h and reintervention within the 1st month. Furthermore, other observed complications encompassed multi-organ failure, unspecified bronchopneumonia, acute renal failure, ventilatory failure with coma, leukoencephalopathy, and acute myocardial infarction. Post-operative complications were additionally classified using the Clavien-Dindo classification, which standardizes the assessment of surgical adverse event severity.[16] The primary outcome measure was all-cause mortality following liver transplantation, assessed both during hospitalization and throughout the follow-up period. Mortality was ascertained through institutional medical records and follow-up telephone communications, conducted as part of the liver transplant program's ongoing surveillance. To determine mortality, hospital records and updated medical histories were reviewed at each follow-up visit.

Data sources

The information was obtained from medical records, including surgical notes, progress notes, and outpatient consultations documented by healthcare personnel. These data are stored in the transplant center of excellence's database, maintained on the research electronic data capture platform under project PID 690.[17,18] To minimize information bias and ensure data quality, strategies such as double data entry, cross-validation of records, and training of personnel responsible for data extraction were implemented.

Statistical analysis

The descriptive analysis was performed first, assessing normality using the Kolmogorov-Smirnov test. The median was calculated, along with the interquartile ranges. Categorical variables were presented as frequencies and percentages. A bivariate analysis was conducted using mortality as the outcome variable, applying the X^2 test for categorical variables, and the Mann-Whitney U test for those continuous without a normal distribution. A multivariate logistic regression model was developed to identify independent predictors of mortality. Variable selection followed a backward elimination approach, initially including factors with a $p < 0.25$. Only variables with a $p < 0.05$ were retained in the final analysis. Model fit was assessed using the Hosmer-Lemeshow test and the pseudo R^2 statistic.

Furthermore, a survival analysis was performed using the Kaplan-Meier estimator to evaluate the probability of developing complications over time (mortality, graft rejection, biliary and vascular complications). Survival data of liver transplant patients were analyzed across four different periods: 2011-2014, 2015-2018, 2019-2022, and 2023-2025. Comparisons between these periods were performed using the log-rank test to assess differences in survival distributions. All analyses were conducted using RStudio software and Stata version 16 (StataCorp, College Station, TX, USA).

Results

A total of 109 patients who underwent liver transplantation were analyzed, of whom 76 (67%) survived, and 33 (33%) died, mostly of men (63.3%) with a global median of age of 53 years (range: 42-63). Most patients are affiliated with the contributory health insurance system (60.6%), followed by the subsidized system (33.9%). Regarding education, the majority completed primary or secondary school (31.2% each), while 21.1% have professional, technical (9.17%), or postgraduate education (0.91%), 41.3% were married, and 89.9% live in urban areas (Table 1).

In the bivariate analysis, the mean age was significantly higher in patients who died during the follow-up after liver transplantation compared to those who survived (59 vs. 51.5; $p = 0.031$). A higher proportion of surviving patients were affiliated with the subsidized healthcare regime (36.8%) compared to those who died (27.7%; $p = 0.031$). In addition, a greater proportion of surviving patients had secondary or technical education compared to those who died (51.2% vs. 15.1%, respectively; $p < 0.001$) (Table 1).

When evaluating the personal and family history of patients with liver transplant, alcohol consumption was reported by 49.54%, while 78.89% had never smoked. Diabetes (22.94%), obesity (11.01%), and

Table 1. Sociodemographic characteristics of patients with liver transplant

Variable	Alive	Deceased	Total	p
	n = 76 (%)	n = 33 (%)	n = 109 (%)	
Sex				
Female	29 (38.1)	11 (33.3)	40 (36.7)	0.631
Male	47 (61.8)	22 (66.6)	69 (63.3)	
Age*	51.5 (40.5-60.0)	59 (47-63)	53 (42-63)	0.031
Type of security and social				
Contributory	45 (59.2)	21 (63.6)	66 (60.6)	0.031
Subsidized insurance	28 (36.8)	9 (27.7)	37 (33.9)	
Particular	3 (3.95)	0 (0.00)	3 (2.75)	
Other	0 (0.00)	3 (9.09)	3 (2.75)	
Level of education				
Primary	22 (28.9)	12 (31.1)	34 (31.2)	< 0.001
Secondary	30 (39.4)	4 (12.1)	34 (31.2)	
Technical	9 (11.8)	1 (3.03)	10 (9.17)	
Professional	15 (19.7)	8 (24.2)	23 (21.1)	
Postgraduate	0 (0.00)	1 (3.03)	1 (0.91)	
No information	0 (0.00)	7 (6.42)	7 (6.42)	
Marital status				
Single	22 (28.5)	5 (15.1)	27 (24.8)	0.386
Married	27 (35.3)	18 (54.5)	45 (41.3)	
Separated	4 (5.26)	1 (3.03)	5 (4.59)	
Widowed	2 (2.63)	2 (6.06)	4 (3.67)	
Common law union	19 (25.0)	6 (18.1)	25 (22.9)	
Not disclosed	2 (2.63)	1 (3.03)	3 (2.75)	
Area of residence				
Rural	9 (11.8)	2 (6.06)	11 (10.1)	0.357
Urban	67 (88.1)	31 (93.4)	98 (89.9)	
Occupation				
Home	21 (27.6)	10 (30.3)	31 (28.4)	0.535
Unemployed	6 (7.89)	1 (3.03)	7 (6.42)	
Business person	8 (10.53)	2 (6.06)	10 (9.17)	
Employee	12 (15.7)	3 (9.09)	15 (13.8)	
Independient	14 (18.4)	8 (24.4)	22 (20.2)	
Others	15 (19.7)	8 (24.4)	23 (21.1)	
Disability pensioner	0 (0.00)	1 (3.03)	1 (0.91)	

*Median. IQR: interquartile range.

cirrhosis (49.54%) were common, with no significant differences between groups. Notably, Hepatitis B was more frequent in survivors (15.79% vs. 3.03%; p = 0.050). Other comorbidities, including heart failure and dyslipidemia, were only present in patients who did not survive (Table 2).

In the analysis of clinical outcomes and post-transplant complications, the median total ischemia time was 393 min (321-515), with cold ischemia at 343 min (280-440) and warm ischemia at 60 min (50-67), showing no significant differences between groups. All transplants were from deceased donors, and 8.26% of patients required re-transplantation. A significantly higher occurrence of rejection was observed in deceased patients (30.30%) compared to survivors (13.15%) (p = 0.034). Other post-transplant complications were significantly more common in deceased patients (45.45%) compared to survivors (17.10%) (p < 0.001). Reintervention percentages due to bleeding (11.92%), post-operative bleeding at 48 h (11.01%), and re-intervention within the 1st month (27.78%) were higher in deceased patients (33.33%), but without significant differences between groups (Table 3). Similarly, according to the Clavien-Dindo, the majority were classified as grade IIIb (52.14%), followed by IIIa (25.64%) and IVa (11.11%). Grade II complications accounted for 5.98%, while the most severe events – grades IVb and V – each represented 2.56% of the total (Table 4).

Table 2. Personal and family history of patients with liver transplant

Variable	Alive n = 76 (%)	Deceased n = 33 (%)	Total n = 109 (%)	p
Personal history				
Alcohol consumption				
Daily consumption	18 (23.68)	10 (30.30)	28 (25.69)	0.807
Occasional consumption	7 (9.21)	4 (12.12)	11 (10.09	
Weekly consumption	11 (14.47)	4 (12.12)	15 (13.76)	
Does not consume	40 (52.63)	15 (45.45)	55 (50.46)	
Smoking history				
Former smoker	13 (17.11)	8 (24.24)	21 (19.27)	0.484
Never smoked	61 (80.26)	25 (75.76)	86 (78.89)	
Currently smokes	2 (2.63)	0	2 (1.83)	
Diabetes	15 (19.74)	10 (30.30)	25 (22.94)	0.228
Dyslipidemia	4 (5.26)	0	4 (3.67)	0.231
Obesity	7 (9.21)	5 (15.15)	12 (11.01)	0.275
Hepatitis A	1 (1.32)	0 (0.00)	1 (0.92)	0.697
Hepatitis B	12 (15.79)	1 (3.03)	13 (11.93)	0.050
Hepatitis C	4 (5.26)	1 (3.03)	5 (4.59)	0.521
Unspecified hepatitis	9 (11.84)	4 (12.12)	13 (11.93)	0.598
Heart failure	2 (2.63)	0	2 (1.83)	0.484
Myocardial infarction	1 (1.32)	1 (3.03)	2 (1.83)	0.516
Cirrhosis	39 (51.32)	15 (45.45)	54 (49.54)	0.574
Family history				
Liver cancer	1 (1.32)	0	1 (0.92)	0.697
Pancreatic cancer	1 (1.32)	0	1 (0.92)	0.697
Other cancer	1 (1.32)	0	1 (0.92)	0.697

Daily consumption: more than 7 drinks per week; Occasional consumption (less than once a week); Weekly consumption (1-7 drinks per week); Former smoker (quit more than 6 months ago).

During the 2011-2014 period, the 1-year survival percent was 63.3% (95% confidence interval [CI]: 43.6-77.7%), with a progressive decline in the first 6 months post-transplant. For the 2015-2018 period, the 1-year survival percentage improved to 84.2% (95% CI: 58.6-94.6%). In the 2019-2022 period, the 1-year survival percentage was 74.1% (95% CI: 48.5-88.3%), showing a slight decrease compared to the 2015-2018 period. Finally, during the 2023-2025 period, the 1-year survival percentage reached 89.1% (95% CI: 73.4-95.7%) (p = 0.093) (Fig. 1).

Kaplan-Meier survival analysis assessed the cumulative incidence of graft rejection across four periods: 2011-2014, 2015-2018, 2019-2022, and 2023-2025, with a 365-day follow-up. The probability of remaining rejection-free at 1 year was 70.4% (95% CI: 49.4-84.0) in the 2011-2014 cohort (n = 29), with a decline within the first 100 days (100-74.3%). In 2015-2018 (n = 19), rejection-free survival improved to 1 year at 78.6% (95% CI: 52.5-91.4), stabilizing after the first 100 days. The 2019-2022 cohort (n = 20) exhibited a further increase to 88.2% (95% CI: 59.8-96.9), with fewer early rejection events. Notably, in 2023-2025 (n = 40), rejection-free survival reached 100%, with no recorded rejection events, suggesting significant advancements in graft survival outcomes, p = 0.009 (Fig. 2).

Biliary and vascular complication-free survival varied across periods. For biliary complications, survival declined to 70.0% at 365 days (95% CI: 48.7-83.8%) in 2011-2014, 67.1% (95% CI: 40.9-83.7%) in 2015-2018, 70.3% (95% CI: 41.9-86.7%) in 2019-2022, and improved to 91.4% (95% CI: 75.7-97.2%) in 2023-2025 (p = 0.076) (Fig. 3A). Vascular complication-free survival followed a similar pattern: 89.4% at 31 days (95% CI: 70.6-96.5%) in 2011-2014, 89.16% (95% CI: 63.2-97.2%) in 2015-2018, 90.0% (95% CI: 65.6-97.4%) in 2019-2022, and 92.4% (95% CI: 78.1-97.5%) in 2023-2025, p = 0.975 (Fig. 3B).

The cold ischemia time (in blue) shows a gradual reduction over the periods, with medians of 461.50 min in 2011-2014, 398.00 min in 2015-2018, 395.50 min in 2019-2022, and 319.00 min in 2023-2025, indicating a decreasing trend in this parameter (p < 0.001). On the other hand, the warm ischemia time (in brown) remains relatively stable across the different periods, with

Table 3. Clinical outcomes and post-transplant complications in liver transplant patients

Variable	Alive n = 76 (%)	Deceased n = 33 (%)	Total n = 109 (%)	p
Ischemia times (min)	385 (320-504.5)	440 (330-515)	393 (321-515)	0.856
Cold*	330.5 (271-435)	405 (307.5-456)	343 (280-440)	0.166
Warm*	60 (50-67)	59 (52.5-65)	60 (50-67)	0.856
Transplant outcomes				
Re-transplantation	6 (7.89)	3 (9.09)	9 (8.26)	0.550
Transplant classification				
Adult	72 (94.74)	31 (93.94)	103 (94.50)	0.591
Pediatric	4 (5.26)	2 (6.06)	6 (5.50)	
Donor type				
Living	0	0	0	
Deceased	76 (100)	33 (100)	109 (100)	0.034
Rejection occurrence	10 (13.15)	10 (30.30)	20 (18.35)	
Rejection type				
Acute	5 (6.57)	7 (21.21)	12 (11.01)	0.325
Chronic	5 (6.57)	3 (9.09)	8 (7.34)	
Rejection cause				
Treatment adherence	2 (2.63)	0	2 (1.83)	0.306
Administrative (insurance- related)	1 (1.31)	0	1 (0.92)	
Subtherapeutic drug levels	1 (1.31)	0	1 (0.92)	
Other	1 (1.31)	2 (6.06)	3 (2.75)	
Biliary complications				
Stricture	9 (11.84)	9 (27.27)	18 (16.51)	0.645
Bile leaks	0 (0.00)	2 (6.06)	2 (1.83)	
Other	3 (3.94)	2 (6.06)	5 (4.59)	
Other complications	13 (17.10)	15 (45.45)	28 (25.69)	< 0.001
Post-transplant re interventions				
Reintervention due to bleeding	8 (10.52)	5 (15.15)	13 (11.92)	0.528
Reintervention due to bleeding at 48 h	8 (10.52)	4 (12.12)	12 (11.01)	0.521
Reintervention within the 1st month	19 (25.00)	11 (33.33)	30 (27.78)	0.321

*Median. IQR: interquartile range.

Table 4. Complications according to the Clavien-Dindo classification

Classification	Number of complications	%
II	7	5.98
IIIa	30	25.64
IIIb	61	52.14
IVa	13	11.11
IVb	3	2.56
V	3	2.56
Total	117	100

values close to 35 min, suggesting that there have been no significant changes in this variable (p = 0.028). Regarding the total ischemia time (in green), a progressive reduction is observed, decreasing from 605.00 min in 2011-2014 to 579.00 min in 2023-2025 (p = 0.038) (Fig. 4).

In the logistic regression analysis, the presence of other complications was identified as an independent predictor of mortality in patients undergoing liver transplantation (Odds ratio = 4.28, p = 0.002) (95% CI: 1.71-10.68). Besides, patients who experienced post-transplant complications were 4.28 times more likely to die compared to those without complications. The overall model was statistically significant (Likelihood-ratio X^2 [1] = 9.83, p = 0.0017), although it explained a relatively small proportion of the variance in mortality (Pseudo R^2 = 0.0749) p < 0.001.

Discussion

The evolution of liver transplant outcomes reflects a significant improvement in the transplant team's

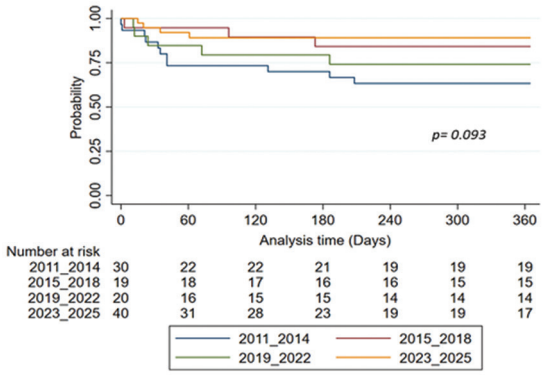

Figure 1. *Kaplan-Meier survival curves for mortality within 1 year after liver transplant. Cumulative survival probability within 1-year post-liver transplantation, comparing different time periods. The number of patients at risk is shown at time intervals.*

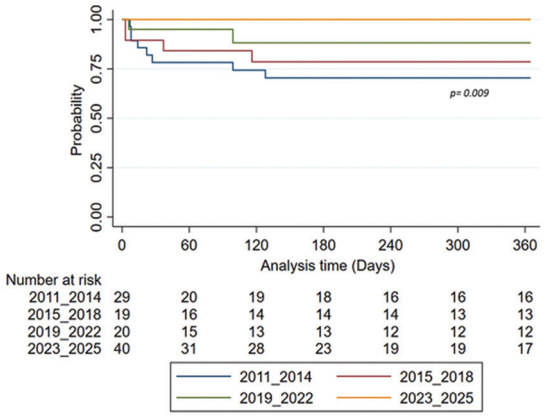

Figure 2. *Kaplan-Meier Survival curves for graft rejection within 1 year after liver transplant. Cumulative probability of freedom from graft rejection within 1-year post-liver transplantation, comparing different time periods. The number of patients at risk is presented at time intervals.*

experience, leading to better clinical results and increased survival probabilities. In our study, the median age was 7.5 years higher in patients who died compared to those who survived, with a statistically significant difference, similar to findings reported by Su et al.[19] One-year survival consistently improved, rising from 63.3% in 2011-2014 to 89.1% in 2023-2025. Comparable results were observed in a meta-analysis by Barbetta et al., showing the same trend over time.[20] This increase indicates advancements in patient selection, optimization of surgical procedures, and greater efficacy in post-operative management. Likewise, Colombian transplant centers have reported improved perioperative protocols and early detection of complications, contributing to better outcomes.[21] The findings from other Latin American transplant centers further support the regional advancement of transplantation practices. For instance, a recent publication by Varón-Vega et al. presents the experience of a high-altitude lung transplant center in Bogotá, Colombia, offering valuable insights into the development and consolidation of complex transplant programs in resource-constrained settings across Latin America.[22] These institutional reports highlight the importance of local expertise, multidisciplinary care, and adaptability in improving outcomes and building sustainable transplant programs in the region.

A notable finding in this study is the progressive reduction in cold ischemia time, with the median duration decreasing from 461.5 min in the 2011-2014 period to 319.0 min in 2023-2025. This trend reflects advancements in organ preservation protocols and logistical efficiencies in transplantation. In contrast, warm ischemia time remained relatively stable, and its variation did not show a significant association with patient mortality. This result is consistent with previous reports, suggesting that while minimizing cold ischemia time is essential for graft viability and long-term outcomes, variations in warm ischemia time within clinically acceptable limits may not have a substantial impact on post-transplant survival.[23,24]

An improvement in rejection prevention was evident, with a lower incidence observed among surviving patients compared to those who did not survive during the studied periods. The absence of rejection episodes within the 1st year post-transplant, observed in the most recent evaluation period, reflects advancements in immunosuppressive management and post-transplant care. Optimized immunosuppressive protocols, tailored treatment strategies, and strict adherence to follow-up regimens have likely contributed to these findings. Research in Latin America has demonstrated that personalized immunosuppressive approaches play a crucial role in reducing rejection rates and prolonging graft survival. These results emphasize the need for ongoing refinement of immunosuppressive therapies and patient monitoring to enhance long-term transplant success.[25,26]

Besides, patients who experienced post-transplant complications were 4.28 times more likely to die compared to those without complications, highlighting the need to further strengthen strategies for the prevention and management of these complications.[27] This finding underscores the importance of close monitoring during the 1st post-operative month, particularly given that vascular and biliary complications primarily

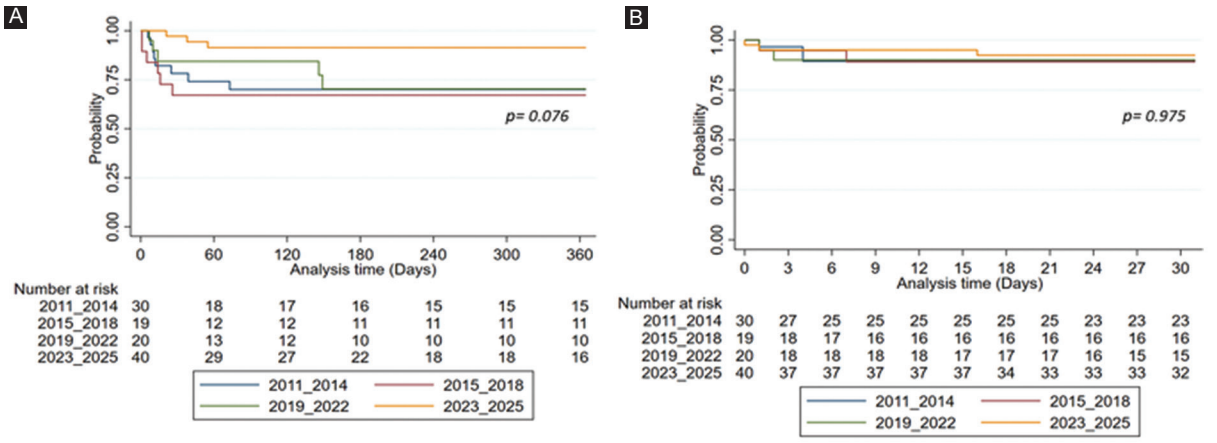

Figure 3. A *and* **B:** *Kaplan-Meier survival curves for biliary and vascular complication. Kaplan-Meier survival analysis for the absence of complications at 1 year (biliary) and 1 month (vascular) following liver transplantation.*

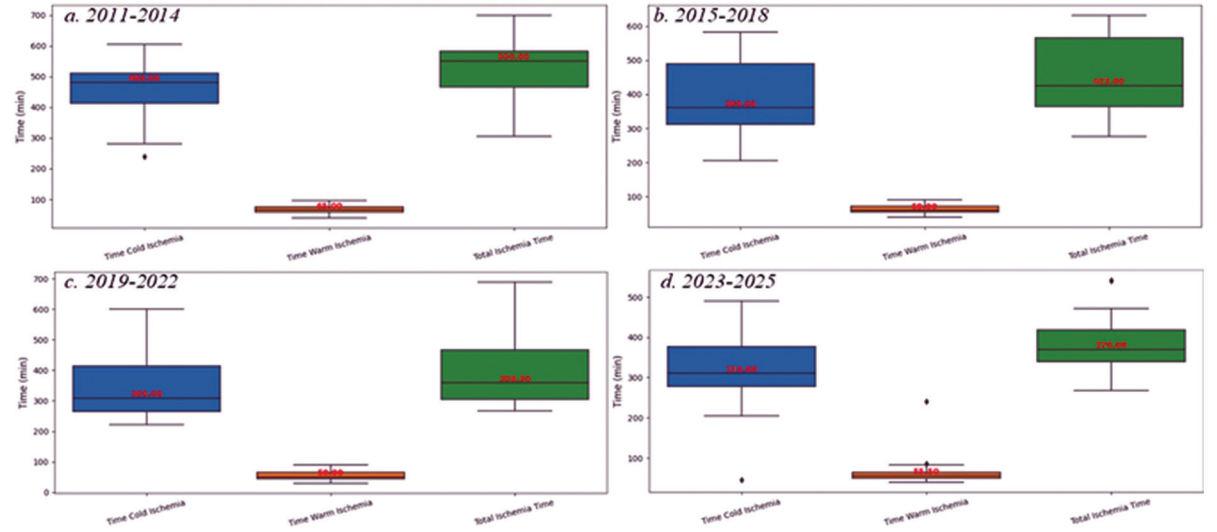

Figure 4. *Cold, warm, and total ischemia times in liver transplantation. The boxplots show the evolution of cold, warm, and total ischemia times over four distinct periods; they show a general trend of improvement in ischemia times, with notable consistency in warm ischemia time.*

occurred during this period.[7] Period-based analysis also reveals a decrease in the incidence of rejection and an improvement in survival, which may be attributed to the accumulated clinical experience of the treating team, the adoption of new technologies, and enhancements in perioperative management protocols.[28] In Colombia, hospitals implementing multidisciplinary post-transplant follow-up programs have reported a significant reduction in early post-operative complications and better long-term patient outcomes.[29]

It is also important to consider the potential influence of the COVID-19 pandemic on post-transplant outcomes, particularly in the earlier years of the 2020s. Several studies have reported that patients with underlying liver disease, including cirrhosis or metabolic-associated fatty liver disease, faced increased risks of severe COVID-19 and mortality, which may have indirectly affected transplant survival rates during that period. In addition, drug-induced liver injury and systemic inflammatory responses related to SARS-CoV-2 have been implicated in liver dysfunction, complicating the clinical course of transplant recipients. The heightened vulnerability of these patients to infections, immune dysregulation, and liver injury during the pandemic years could have contributed to increased post-transplant morbidity and mortality, warranting further investigation in future studies.[30]

These findings reaffirm that the accumulated experience over the years has been a key factor in improving liver transplant outcomes.[31] It is recommended to continue optimizing ischemia times, strengthening measures to prevent acute rejection, and refining strategies to reduce post-operative complications. Future research should focus on identifying prognostic factors that enhance the accuracy of rejection and post-operative complication risk prediction, as well as evaluating the impact of novel immunosuppressive therapies and surgical techniques on long-term outcomes. In addition, comparative studies between different transplant centers in Latin America could provide valuable insights into best practices and opportunities for standardizing care protocols across the region.[32]

This study has some limitations inherent to its retrospective design, as well as the fact that the data come from a single institution, which may restrict the generalizability of the findings to other settings. Nevertheless, it has several strengths. It provides a detailed analysis of long-term outcomes in liver transplant patients, supported by a rigorous follow-up protocol and a multidisciplinary approach.

Conclusions

The results of this study demonstrate a progressive improvement in 1-year survival, along with a reduction in rejection incidence, suggesting advances in post-transplant management. However, post-transplant complications, excluding biliary and vascular complications, remain a significant risk factor for mortality. Finally, the progressive reduction in cold and total ischemia times reflects an optimization of surgical and logistical procedures in liver transplantation.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of human subjects and animals. The authors declare that the procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the World Medical Association and the Declaration of Helsinki. The procedures were authorized by the Institutional Ethics Committee.

Confidentiality, informed consent, and ethical approval. The study was approved by the Research Ethics Committee (REC) of the Fundación Cardiovascular de Colombia under the approval code CEI-2024-016-8. All patient data were anonymized to ensure confidentiality, and the study was conducted in accordance with the principles outlined in the Declaration of Helsinki. This article complies with the provisions set forth in Resolution 008430 of 1993 by the Ministry of Health of Colombia, which establishes guidelines for the protection of the rights of research subjects in scientific studies. Informed consent was obtained from all participants before their inclusion in the study, and no identifiable information was disclosed in this publication. The datasets generated and analyzed during the study are available on reasonable request from the corresponding author.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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