

Long-term cardiovascular adverse events in liver transplant recipients with over 10 years of survival: incidence, temporal pattern and preoperative risk factors

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Abstract

Objective

To explore the incidence, temporal distribution, and preoperative predictors of major adverse cardiovascular events (MACE) among liver transplant recipients with more than 10 years of post-transplant survival.

Methods

This single-center retrospective cohort study enrolled 52 eligible primary liver transplant recipients operated between 2013 and 2015. We collected complete preoperative, intraoperative, and long-term follow-up data via outpatient records and telephone follow-up. MACE was defined as new-onset coronary heart disease, cerebrovascular disease, or peripheral arterial occlusive disease. The Kaplan–Meier method and log-rank test were used to calculate cardiovascular event-free survival and compare intergroup differences. Firth-corrected univariable and multivariable binary logistic regression were performed to screen preoperative risk factors, and Fisher’s exact test was applied to compare MACE incidence across different immunosuppressive regimens.

Results

Among the 52 ultra-long-term survivors, the cumulative incidence of MACE reached 13.5% (7 patients, 8 documented vascular events). Most cardiovascular events occurred 5–10 years after transplantation, and 28.6% of new MACE emerged beyond the 10-year postoperative mark. The 5-year, 10-year, and post-10-year cardiovascular event-free survival rates were 98.1%, 90.4%, and 85.5%, respectively. Log-rank analysis showed that only preoperative hypertension was significantly associated with poorer cardiovascular event-free survival ($P = 0.0012$). Multivariate regression further confirmed preoperative hypertension as the sole independent risk factor for long-term MACE (OR = 15.16, 95%CI:1.96–219.90, $P = 0.009$). No significant intergroup difference in MACE incidence was detected among various immunosuppressive protocols ($P = 0.590$).

Conclusion

Liver transplant survivors carry sustained long-term cardiovascular risks, with a notable proportion of atherosclerotic events developing in the late post-transplant period. Preoperative hypertension independently predicts long-term MACE after liver transplantation. Lifelong standardized cardiovascular surveillance and intensive blood pressure control are essential to reduce atherosclerotic cardiovascular burden in this high-risk population.

Introduction

Liver transplantation remains the definitive therapeutic modality for end-stage liver disease (ESLD) [1], with remarkable improvements in short-term patient and graft survival over recent decades. However, accumulating evidence demonstrates that multiple adverse factors, including long-term immunosuppressive exposure, preoperative persistent metabolic abnormalities, chronic systemic inflammation, and post-transplant hemodynamic changes, synergistically induce vascular endothelial injury and accelerate atherosclerotic progression[2]. Accordingly, cardiovascular diseases have become the leading non-graft-related causes of mortality and impaired quality of life among ultra-long-term liver transplant survivors[3–5]. However, most existing studies focus on cardiovascular events within the first 5 years after liver transplantation, with few reports extending follow-up beyond 10 years[6, 7]. The temporal pattern of ultra-long-term cardiovascular events and the predictive value of preoperative baseline factors remain incompletely characterized [8].

This study presents a single-center retrospective cohort with complete follow-up exceeding 10 years, aiming to describe the incidence and time distribution of major adverse cardiovascular events (MACE), and identify independent preoperative risk factors. The findings may provide real-world evidence to optimize lifelong cardiovascular risk stratification and management strategies for liver transplant recipients.

Data and methods

Study Population

This retrospective cohort analysis included liver transplant recipients who underwent transplantation at Beijing Friendship Hospital, Capital Medical University, between April 2013 and December 2015. Inclusion criteria were: (1) age ≥ 18 years; (2) successful primary isolated liver transplantation; (3) complete clinical follow-up for ≥ 10 years postoperatively with intact medical records, imaging data, and medication profiles; (4) no preoperative history of severe cardiovascular or cerebrovascular or peripheral arterial disease.

Exclusion criteria included: (1) re-transplantation or combined multi-organ transplantation; (2) postoperative mortality within 10 years after transplantation; (3) loss to follow-up or severely missing clinical data; (4) history of autoimmune vasculitis or psychiatric disorders interfering with long-term follow-up; (5) history of non-hepatic malignancies.

Observation Indicators

All clinical data were independently extracted from the institutional electronic medical record system and dedicated liver transplantation follow-up database by two qualified investigators, and cross-validated against these sources. Collected variables were categorized into six domains: (1) baseline

demographic characteristics, including gender, age, body mass index (BMI), smoking history, and drinking history; (2) preoperative laboratory biomarkers, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), serum albumin, total bilirubin, serum creatinine, fasting blood glucose (FBG), total cholesterol (TC), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), international normalized ratio (INR), and preoperative Model for End-Stage Liver Disease (MELD) score; (3) preoperative comorbidities, including hypertension, type 2 diabetes mellitus, hyperlipidemia, and chronic kidney disease; (4) surgical and etiological parameters, including ESLD etiology, donor type, surgical approach, cold ischemia time, and total operative duration; (5) postoperative immunosuppressive regimens; (6) vascular complication-related indicators, including confirmed onset time, clinical classification, diagnostic basis via imaging and laboratory tests.

The primary endpoint was MACE, defined as new-onset coronary heart disease, ischemic cerebrovascular disease, or peripheral arterial occlusive disease confirmed by clinical imaging or specialist diagnosis during follow-up. Coronary heart disease was defined as $\geq 50\%$ stenosis of major coronary arteries, confirmed by coronary computed tomography angiography (CCTA) or invasive coronary angiography (CAG)[9]. Cerebrovascular disease including ischemic stroke, cerebral hemorrhage, and transient ischemic attack, was diagnosed via cranial computed tomography (CT) or magnetic resonance imaging (MRI). Peripheral arterial disease including a spectrum of peripheral arterial stenosis lesions ($\geq 50\%$ luminal narrowing) was verified by vascular ultrasound, computed tomography angiography, or digital subtraction angiography (DSA)[10]

Statistical Analysis

Normally distributed continuous variables were presented as mean $\pm$ SD (standard deviation) and compared via independent samples t-test; non-normally distributed continuous variables were expressed as median (interquartile range, IQR) and analyzed using the Mann-Whitney U test. Categorical variables were reported as case counts (percentages) [n (%)], with intergroup comparisons conducted using the chi-square test or Fisher's exact test when the cell count was less than 5.

The Kaplan-Meier method was applied to generate vascular MACE-free survival curves, and the log-rank test was used to compare survival differences between subgroups stratified by preoperative clinical indicators. Considering the limited number of endpoint events in this cohort, Firth-corrected binary logistic regression was adopted via the `logistf` package in R was adopted to avoid estimation bias due to complete data separation and small sample size. All variables with $P \leq 0.20$ in univariate analysis, along with clinically important confounding factors (age, gender, BMI, smoking, diabetes mellitus) were enrolled into multivariate regression model to screen independent preoperative risk factors for vascular complications. Additionally, Fisher's exact test was used to analyze the association between different immunosuppressive regimens and postoperative vascular complication incidence. A two-sided P value < 0.05 was considered statistically significant for all analyses. All statistical analyses were performed using SPSS 27.0 and R 4.6 software.

Use of Large Language Model

The Doubao large language model (ByteDance) was used for English language polishing and manuscript text editing. The study design, data analysis, interpretation of results and core conclusions were all completed by the authors independently.

Results

Baseline characteristics

We initially screened 114 consecutive liver transplant recipients who underwent primary liver transplantation during the study period. Patients with re-transplantation ($n = 6$), all-cause mortality within 10 years post-transplantation ($n = 43$), and incomplete clinical data or loss to long-term follow-up ($n = 13$) were excluded. Ultimately, 52 patients with complete clinical datasets and postoperative survival exceeding 10 years were enrolled in the final cohort. The cohort consisted of 34 male (65.4%) and 18 female (34.6%) patients, with a median age of 52 years (IQR 42–59) and a mean BMI of 23.9 ± 3.5 kg/m². The median preoperative MELD score was 10.5 (IQR 8–15). Preoperative comorbidities included hypertension (11.5%), type 2 diabetes mellitus (17.3%), and hyperlipidemia (1.9%). Additionally, 34.6% of patients had a history of smoking, and 30.8% had a history of drinking.

The primary etiology of ESLD was viral hepatitis cirrhosis (53.8%), including 26 cases of hepatitis B virus-related cirrhosis and 2 cases of hepatitis C virus-related cirrhosis; this was followed by cholestatic liver disease (21.2%), alcoholic cirrhosis (13.5%), autoimmune liver disease (5.8%), idiopathic portal hypertension (3.8%), and Budd-Chiari syndrome (1.9%). The majority of patients received cadaveric donor liver transplantation (94.2%), while 5.8% received living donor liver transplantation. Orthotopic liver transplantation was the predominant surgical approach (92.3%), and the remaining 7.7% underwent piggyback liver transplantation. Baseline comparisons between complication and non-complication subgroups are summarized in Table 1. Patients with MACE had a significantly higher prevalence of preoperative hypertension and hyperlipidemia compared with those without events ($P = 0.005$ and $P = 0.01$, respectively).

Table 1

Baseline clinical characteristics of the 52 enrolled liver transplant recipients stratified by postoperative cardiovascular complication status

Variables	Overall (n = 52)	MACE (n = 7)	No MACE (n = 45)	P value
Age (years), median (IQR)	52 (42–59)	60 (49–63)	52 (40.5–57)	0.212
Male, n (%)	34 (65.4)	5 (71.4)	29 (64.4)	0.718
BMI (kg/m ²), mean ± SD	23.9 ± 3.5	22.98 ± 4.72	24.06 ± 3.29	0.451
Hypertension, n (%)	6 (11.5)	3 (50.0)	3 (6.7)	0.005*
Type 2 diabetes mellitus, n (%)	9 (17.3)	2 (28.6)	7 (15.6)	0.397
Hyperlipidemia, n (%)	1 (1.9)	1 (14.3)	0 (0.0)	0.010*
Chronic kidney disease, n (%)	1 (1.9)	0 (0.0)	1 (2.2)	0.690
Smoking history, n (%)	18 (34.6)	2 (28.6)	16 (35.6)	0.718
Drinking history, n (%)	16 (30.8)	3 (42.9)	13 (28.9)	0.456
MELD score, median (IQR)	10.5 (8–15)	12 (6–14)	10 (8–15)	0.563
ALT (U/L), median (IQR)	24.5 (15.3–51.5)	15 (13–24)	28 (17–54.7)	0.114
AST (U/L), median (IQR)	30.5 (19.6–62.8)	26 (13–33)	32 (19.9–74.5)	0.217
Albumin (g/L), median (IQR)	40.3 (33.5–43.8)	44.3 (33.6–45.0)	40.2 (32.6–43.3)	0.529
Total bilirubin (μmol/L), median (IQR)	23.0 (14.1–56.2)	22.15 (16.7–55.0)	23.22 (13.7–57.6)	0.989
Creatinine (μmol/L), median (IQR)	69.9 (60.4–86.3)	67.4 (54.8–73.3)	71 (62.4–96.3)	0.203
FBG (mmol/L), mean ± SD	5.5 ± 1.1	6.23 ± 1.79	5.44 ± 1.00	0.090
TC (mmol/L), median (IQR)	4.3 (3.4–4.7)	4.20 (3.40–4.50)	4.31 (3.30–4.70)	0.799
Triglyceride (mmol/L), median (IQR)	1.1 (0.8–1.8)	1.05 (0.80–1.50)	1.13 (0.80–2.00)	0.968
HDL-C (mmol/L), mean ± SD	1.2 ± 0.5	1.19 ± 0.38	1.17 ± 0.54	0.915
LDL-C (mmol/L), mean ± SD	2.3 ± 0.9	2.34 ± 0.68	2.28 ± 0.92	0.860
Cadaveric/Living donor (n)	49/3 (94.2/5.8)	7/0 (100.0/0.0)	42/3 (93.3/6.7)	0.482
*P < 0.05.				

Variables	Overall (n = 52)	MACE (n = 7)	No MACE (n = 45)	P value
Orthotopic/Piggyback surgery (n)	48/4 (92.3/7.7)	7/0 (100.0/0.0)	41/4 (91.1/8.9)	0.412
Cold ischemia time (min), median (IQR)	612 (416–724)	660 (446–725)	600 (405.5–722.5)	0.799
Operation duration (min), median (IQR)	394 (360–499)	380 (375–452)	395 (357.5–505.0)	0.564
*P < 0.05.				

Incidence and temporal distribution of MACE

Over a median follow-up of 11.6 years (range, 10.0–13.0 years), a total of 8 cardiovascular events were recorded in the 7 patients, including 4 cases of coronary heart disease (7.7%), 2 cases of ischemic stroke (3.8%) and 2 cases of peripheral arterial disease (3.8%). One patient experienced two sequential vascular events at different time points: cerebral infarction at 0.5 years post-transplantation and iliac artery occlusion requiring stent implantation at 4.5 years post-transplantation.

The onset of MACE was concentrated in the middle and late post-transplant stages. The 5–10-year postoperative period was the peak incidence window, accounting for 57.1% of all events. Notably, 28.6% of new-onset MACE occurred more than 10 years after transplantation, indicating persistent cardiovascular risk even in ultra-long-term survivors. (Table 2)

Table 2
Temporal distribution of MACE

Complication	Case number	Incidence (%)	≤ 5 years [n (%)]	5–10 years [n (%)]	>10 years [n (%)]
Coronary heart disease	4	7.7	0	2	2
Cerebrovascular disease	2	3.8	1	1	0
Peripheral vascular disease	2	3.8	1	1	0
Total	7*	13.5	1* (14.3)	4(57.1)	2(28.6)
*One single liver transplant recipient developed two sequential vascular events at different time points: cerebral infarction at 0.5 years post-transplantation and iliac artery occlusion at 4.5 years post-transplantation, resulting in a total of 8 vascular adverse events in the 7 complicated cases.					

MACE-free survival analysis

The median time to complication among patients who experienced complications was 11.0 years, with a maximum follow-up of 13.0 years. Kaplan–Meier survival analysis showed that the 5-year, 10-year and overall MACE-free survival rates were 98.1% (95%CI: 94.4%–100.0%), 90.4% (95%CI: 82.7%–98.8%) and 85.5% (95%CI: 76.0%–96.2%), respectively. Owing to an overall event rate of only 13.5%, the median MACE-free survival of the whole cohort could not be calculated (Fig. 1).

When stratified by baseline hypertension status, the log-rank test revealed a highly significant intergroup difference in MACE-free survival ($\chi^2=10.452$, $df = 1$, log-rank $P = 0.0012$). No statistically significant differences were observed across subgroups stratified by age, gender, BMI, serum creatinine, smoking history and MELD score (all log-rank $P>0.05$, Supplementary **Table S1**).

Risk factors for MACE

In univariate Firth-corrected logistic regression analysis, preoperative hypertension (OR = 9.44, 95%CI:1.58–60.37, $P = 0.015$) and fasting blood glucose (OR = 1.61, 95%CI:0.90-3.00, $P = 0.102$) were associated with an increased risk of MACE. All variables with $P\leq 0.2$ in univariate comparison plus clinically meaningful indicators were further included in multivariate Firth-corrected logistic regression analysis (Table 3 and Fig. 2). In multivariate regression, preoperative hypertension was confirmed as the only independent risk factor for ultra-long-term MACE after liver transplantation (OR = 15.16, 95%CI: 1.96–219.90, $P = 0.009$). Preoperative hyperlipidemia showed a trend toward increased cardiovascular risk but did not reach statistical significance, likely due to the limited sample size.

Table 3
Univariate and Multivariate Firth-corrected Logistic Regression Analysis of Preoperative Risk Factors for MACE

Variables	Univariate Analysis		Multivariate Analysis	
	OR (95% CI)	P value	OR (95% CI)	P value
Hypertension	9.44 (1.58–60.37)	0.015*	15.16 (1.96–219.90)	0.009*
FBG (mmol/L)	1.61 (0.90–3.00)	0.102	1.51 (0.72–3.66)	0.276
Hyperlipidemia	21.00 (1.01–3203.87)	0.049		
Age (years)	1.04 (0.97–1.14)	0.269	1.01 (0.94–1.11)	0.760
Male gender	0.81 (0.13–3.82)	0.799	0.77 (0.09–7.31)	0.804
BMI (kg/m ²)	0.84 (0.57–1.12)	0.241	0.83 (0.61–1.05)	0.129
Smoking history	0.81 (0.13–3.82)	0.799	0.62 (0.06–5.38)	0.656
Type 2 diabetes mellitus	2.33 (0.36–12.08)	0.342	1.04 (0.07–9.57)	0.973
LDL-C (mmol/L)	1.11 (0.44–2.56)	0.806		
AST (U/L)	0.99 (0.93–1.01)	0.324		
Creatinine (μmol/L)	0.98 (0.94–1.01)	0.537		
ALT (U/L)	1.00 (0.95–1.01)	0.885		
Drinking history	1.87 (0.37–8.80)	0.429		
Triglyceride (mmol/L)	0.90 (0.29–1.61)	0.762		
MELD score	0.98 (0.82–1.11)	0.800		
Total bilirubin (μmol/L)	1.00 (0.99–1.01)	0.977		
Albumin (g/L)	0.98 (0.92–1.06)	0.549		
HDL-C (mmol/L)	1.13 (0.23–4.83)	0.870		
TC (mmol/L)	1.04 (0.57–1.83)	0.905		
Chronic kidney disease	1.98 (0.01–40.93)	0.701		
*P < 0.05. Multivariate analysis included variables with P ≤ 0.2 in univariate analysis, along with age, male gender, BMI, smoking history, type 2 diabetes mellitus, and LDL-C as specified. Hyperlipidemia was excluded from multivariate analysis due to the extremely small sample size (only 1 case in the entire cohort), which precluded reliable statistical inference.				

Association between immunosuppressive regimens and MACE

The distribution of postoperative immunosuppressive regimens and their association with MACE are summarized in Table 4. Among the 52 enrolled patients, 46 (88.5%) received the standard triple immunosuppressive regimen of tacrolimus + mycophenolate mofetil + glucocorticoid, 4 (7.7%) were on dual therapy with tacrolimus + glucocorticoid, and 2 (3.8%) were treated with cyclosporine A + mycophenolate mofetil + glucocorticoid.

Table 4
Association between immunosuppressive regimens and MACE

Immunosuppressive regimen	Total number (n)	Incidence of vascular complications [n (%)]	P
Tacrolimus + MMF + Glucocorticoid	46	5 (10.9)	0.590
Tacrolimus + Glucocorticoid	4	1 (25.0)	
Cyclosporine A + MMF + Glucocorticoid	2	0 (0.0)	
Total	52	7 (13.5)	
MMF, mycophenolate mofetil			

The event incidence was 10.9% in the triple tacrolimus-based group, 25.0% in tacrolimus + steroid dual group, and 0.0% in cyclosporine-containing triple regimen group. Fisher’s exact test showed no statistically significant inter-group difference in MACE incidence across distinct immunosuppressive protocols (P = 0.590).

Discussion

This study characterized ultra-long-term cardiovascular outcomes in a cohort of liver transplant recipients with over 10 years of complete follow-up. The 13.5% incidence of ultra-long-term MACE in this Chinese liver transplant cohort was lower than the 18% incidence over 5 years reported in past study[7]. Such interstudy heterogeneity may be attributed to ethnic differences in genetic susceptibility, lifestyle characteristics, and baseline metabolic status, as well as the single-center retrospective design and limited sample size of the present study. Furthermore, 28.6% of all MACE in our cohort occurred more than 10 years after transplantation. This finding strongly indicates that post- transplantation cardiovascular injury is a persistent, progressive pathological process, and ultra-long-term liver transplant survivors remain at considerable risk of new-onset cardiovascular events even after sustained postoperative remission.

The persistent cardiovascular risk in ultra-long-term liver transplant survivors can be explained by three core pathological mechanisms: chronic vascular endothelial dysfunction induced by long-term immunosuppressive therapy, incomplete remission of preoperative metabolic disorders after transplantation, and progressive age-related vascular remodeling and stiffening[11]. Therefore, these findings highlight the necessity of continuous lifelong vascular surveillance for all liver transplant recipients, suggesting that clinical monitoring intensity should not be reduced due to long-term postoperative disease-free status[4].

Kaplan-Meier survival analysis demonstrated a favorable overall ultra-long-term cardiovascular prognosis for liver transplant recipients, with an 85.5% MACE-free survival rate in patients with over 10 years of postoperative survival. Hypertension, hyperlipidemia and diabetes mellitus are documented risk factors for cardiovascular diseases[12, 13]. Subgroup stratification identified preoperative hypertension as the only statistically significant negative predictor of ultra-long-term cardiovascular outcomes. In multivariate Firth-corrected logistic regression analysis, preoperative hypertension was confirmed as the sole independent risk factor for ultra-long-term cardiovascular complications. This finding is consistent with the traditional risk factors for cardiovascular diseases in the general population, where hypertension is well-established as the most important modifiable predisposing factor for atherosclerotic vascular lesions[14]. Notably, the only patient with preoperative hyperlipidemia in our cohort developed a cardiovascular complication, and univariate analysis showed a statistically significant association. However, due to the extremely low prevalence of hyperlipidemia (only one case in the entire cohort), we were unable to include this variable in the multivariate analysis to evaluate its independent effect. This finding suggested a potential strong association between preoperative hyperlipidemia and ultra-long-term cardiovascular complications, which requires further validation in larger-scale studies. Additionally, preoperative fasting blood glucose showed a borderline association with increased cardiovascular risk in univariate analysis, but this association was attenuated and no longer statistically significant after multivariate adjustment.

This study did not observe a significant association between different immunosuppressive regimens and the risk of ultra-long-term cardiovascular events, which is partially inconsistent with previous studies. Accumulated clinical evidence demonstrated that, compared with cyclosporine A, tacrolimus is associated with a lower incidence of postoperative hypertension and metabolic disorders, thereby potentially reducing the long-term risk of cardiovascular diseases[7]. However, in our study, the two patients treated with cyclosporine A did not develop any cardiovascular events, while the highest event incidence was observed in the tacrolimus monotherapy group without mycophenolate mofetil. This discrepancy may be mainly attributed to the limited sample size of our study, which leads to insufficient statistical power to detect the potential difference between different immunosuppressive agents. In addition, the short follow-up duration of previous studies mostly focused on cardiovascular events within five years after transplantation[15], while our study focused on ultra-long-term events beyond ten years, which may also be an important reason for the different conclusions.

These findings have direct clinical relevance for both transplant physicians and cardiovascular clinicians. First, preoperative hypertension screening and optimized antihypertensive therapy should be emphasized in the pre-transplant evaluation phase. Second, all long-term liver transplant survivors should be considered a high cardiovascular risk population requiring lifelong systematic surveillance, with intensified screening initiated at 5 years post-transplant to capture the peak onset window. Third, recipients with preoperative hypertension should be stratified into the highest risk tier, with regular monitoring of blood pressure, lipid profiles and vascular status throughout their post-transplant lifespan.

Limitations

Several limitations of this study should be acknowledged. First, this is a single-center retrospective study with a relatively small sample size, which limits statistical power for subgroup analysis and may introduce selection bias. Second, serial postoperative blood pressure and lipid measurements were not included, so the impact of post-transplant metabolic control on cardiovascular outcomes could not be evaluated. Despite these limitations, the ultra-long-term follow-up of over 10 years represents a major strength of this study, providing rare real-world data on late cardiovascular complications after liver transplantation.

Conclusion

Liver transplant recipients face sustained atherosclerotic cardiovascular risk over the long term, with a substantial proportion of major adverse cardiovascular events emerging more than 10 years after transplantation. Preoperative hypertension is the only confirmed independent preoperative risk factor for ultra-long-term cardiovascular events in this study. Lifelong standardized cardiovascular surveillance and targeted intensive blood pressure management are essential to reduce long-term cardiovascular burden and improve late-stage outcomes in this high-risk population.

Abbreviations

MACE

major adverse cardiovascular events

BMI

body mass index

MELD

Model for End-Stage Liver Disease

CI

confidence interval

IQR

interquartile range

OR

odds ratio

ALT
alanine aminotransferase
AST
aspartate aminotransferase
FBG
fasting blood glucose
TC
total cholesterol
HDL-C
high-density lipoprotein cholesterol
LDL-C
low-density lipoprotein cholesterol

Declarations

Ethics approval and consent to participate

The present study employed de-identified patient data and received ethical approval from the Ethics Committee of Beijing Friendship Hospital (Approval No.: 2024-P2-159-01). Given the retrospective observational design and anonymized data analysis, the requirement for individual informed consent was waived by the ethics committee. All procedures were performed in accordance with the 1964 Declaration of Helsinki and its later amendments.

Consent for publication

Not applicable. All patient data were fully anonymized, and no identifiable personal information is included in this manuscript.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

Hui-kuan Gao and Fei Hou contributed equally to this work: study conception and design, data collection, statistical analysis, and manuscript drafting; Lin Wei, Wei Qu, Zhi-gui Zeng: data curation and validation;

Zhi-jun Zhu, Hao-feng Xiong, Li-ying Sun: study supervision, final approval of the manuscript. All authors reviewed and approved the final manuscript.

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Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

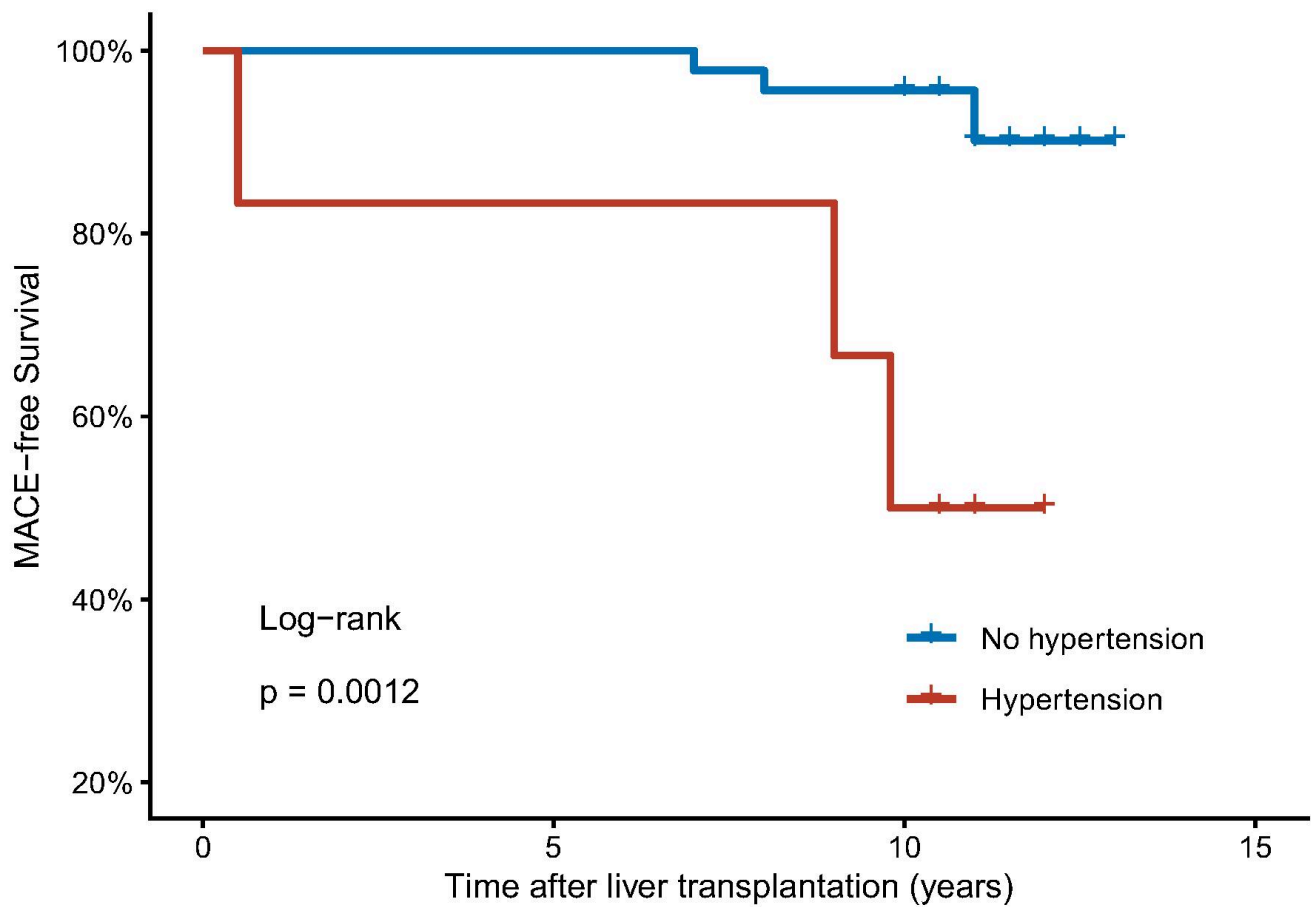


Figure 1

Kaplan-Meier curve for MACE-free survival in 52 liver transplant recipients

MACE-free survival was estimated using the Kaplan–Meier method, and intergroup survival differences were assessed with the log-rank test. Patients with preoperative hypertension had significantly worse complication-free survival compared with normotensive counterparts (log-rank $\chi^2=10.452$, $df=1$, $P=0.0012$).

Multivariate Firth-corrected Logistic Regression Analysis

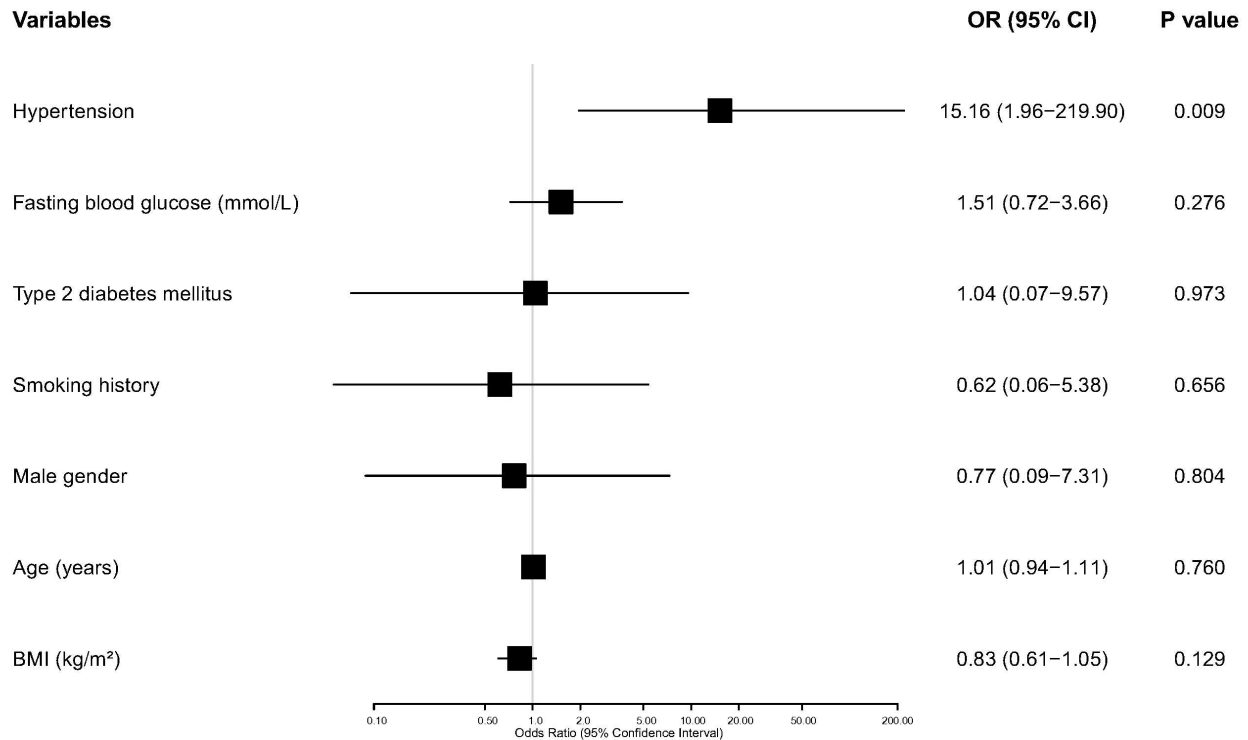


Figure 2

Forest plot from multivariate Firth-corrected logistic regression analysis of preoperative risk factors for MACE

Odds ratios (OR) and corresponding 95% confidence intervals (CI) were calculated via Firth-corrected logistic regression to address small sample bias and complete separation. The vertical dashed line at OR = 1 represents the reference null value for no statistical association. Squares denote the point estimate of OR for each variable, and horizontal lines indicate the 95% CI. Hypertension was confirmed as the only independent risk factor (P=0.009).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [TableS1.docx](#)