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Original Article

Outcomes of living-donor liver transplantation in older patients over 65 and 70 years compared to the younger recipients

Deok-Gie Kim, Young Jin Yoo, Minyu Kang, Hwa-hee Koh, Eun-Ki Min, Jae Geun Lee, Myoung Soo Kim, Dong Jin Joo*

Department of Surgery, The Research Institute for Transplantation, Yonsei University College of Medicine, Seoul, South Korea

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ABSTRACT

Background: As liver transplantation is increasingly considered for older adults with high perioperative risks, this study investigated the outcomes of living donor liver transplantation (LDLT) in older compared to younger recipients.

Methods: A retrospective analysis was performed involving 908 LDLT recipients, categorized by age: ≤64 years (n = 862), 65–69 years (n = 80), and ≥70 years (n = 28). Graft survival and complications were compared between the age groups.

Results: Older recipients (≥65 years) exhibited a high incidence of preexisting conditions including hypertension and diabetes. Five-year graft survival was reduced in older recipients in unmatched analysis (81.8 % in ≤64 years vs. 75.0 % in 65–69 years vs. 69.7 % in ≥70 years, P = 0.045). However, this difference was not significant in multivariable Cox regression (hazard ratio [HR] 1.44, P = 0.156 for 65–69 years and HR 1.69, P = 0.156 for ≥70 years). In matched analyses, graft survival in the 65–69 age group (78.9 % vs. 74.5 %, P = 0.324) and the ≥70 age group (80.3 % vs. 76.0 %, P = 0.551) was not inferior to that of the ≤64 age group. Rejection and surgical complications within 1 year were similar between the groups. However, the incidence of pneumonia was significantly higher in the older group than that in the younger group (11.3 % vs. 20.8 % vs. 19.3 %, P = 0.019).

Conclusion: LDLT in older patients demonstrated survival comparable to that in younger patients when pre-transplant characteristics were adjusted. Patient selection based on comorbidities and infection prevention strategies is critical for optimizing postoperative outcomes in this demographic group.

1. Introduction

As global life expectancy rises, the proportion of older individuals has also increased.[1] This demographic shift has led to an increasing number of older patients with cirrhosis and hepatocellular carcinoma (HCC).[2,3] Consequently, the demand for liver transplantation (LT) has been increasing among older populations, with the proportion of patients over 65 years rising from 9.4 % in 2010 to 21.7 % in 2020 in a United States cohort.[4]

However, performing LT in older patients presents unique challenges. Older recipients often have a high prevalence of comorbidities including sarcopenia. Moreover, in comparison to younger patients, they tend to exhibit reduced physiological reserves and impaired performance status.[5,6] Consequently, older recipients may be susceptible to surgical stress and post-LT complications.[7,8] Furthermore, age-related immunosenescence renders these patients vulnerable to infections following transplantation.[9]

Despite higher perioperative comorbidities, numerous studies have reported that deceased donor liver transplantation (DDLT) in older recipients demonstrated survival rates similar to those observed in younger patients.[7] Nevertheless, older patients inherently have a diminished capacity to cope with disease progression, potentially resulting in high waiting-list mortality.[10] Therefore, the need for living-donor LT (LDLT) has been increasingly recognized in older patients because of the shortage of available organs.

According to several reports comparing patients based on an age threshold of 65 or 70 years, no substantial difference has been

* Corresponding author. Department of Surgery, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul, 03722, South Korea.
E-mail address: djjoo@yuhs.ac (D.J. Joo).

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observed in survival rates.[11–15] However, a discrepancy still exists in the reported inferior LDLT outcomes in older patients.[16–18] Notably, comparative studies focusing on detailed outcomes, including rejection, infection, and surgical complications, between older and younger patients within the LDLT cohort remain limited. Therefore, more evidence is needed to perform LDLT in older adults.

This study aimed to analyze LDLT outcomes in older recipients by conducting a comparative analysis with younger patients to provide further insights into the feasibility and outcomes of LDLT in older populations.

2. Materials and methods

2.1. Study materials

We retrospectively reviewed the data of 1067 adult patients who underwent LDLT at Severance Hospital between July 2005 and December 2023. Recipients of dual living donors (n = 4), LDLT using an right posterior or anterior graft (n = 14), or retransplantation (n = 4) were excluded. Patients with pre-transplant intensive care unit (ICU) stay (n = 24) and alpha-fetoprotein level ≥500 ng/mL or protein induced by vitamin K absence or antagonist-II ≥500 mAU/mL (n = 47) were also excluded, as none of the patients over ≥65 years of age had these conditions. Overall, 908 eligible LDLT recipients were included in the analysis (Fig. 1). Data were extracted from the institutional LT database and obtained from electronic medical records.

2.2. Definition and outcomes

There was no strict age cutoff for LT; although referrals included patients over 80, the oldest recipients at our center were 76 for LDLT. LT decisions were based on physiological age and functional status rather than chronological age. Patients were grouped based on recipient age into three distinct categories: ≤64 years (n = 862), 65–69 years (n = 80), and ≥70 years (n = 28). Preoperative morbidity was adjusted using the Model for End-Stage Liver Disease (MELD) score, categorized into intervals of 10-point increments to standardize patient risk before LT. Donor liver graft steatosis was evaluated intraoperatively and classified into two categories: ≤10 % or >10 %, based on pathological analysis. The graft-to-recipient weight ratio (GRWR) was determined using the following formula: GRWR = (graft weight [g]/recipient weight [g]) × 100, with graft weight measured immediately before graft implantation. Serial trough levels of serum tacrolimus were obtained to compare the potency of immunosuppression between age groups.

Post-transplant outcomes were assessed by examining the duration of postoperative ICU stay, length of hospital stay until discharge, and readmission within 180 days after LDLT. Complications occurring within 1 year post-LT were classified into the following categories: rejection, hepatic artery complications, portal vein complications, hepatic vein complications, bile leaks, and bile duct strictures. Infections were documented based on the identified pathogens, including bacterial, fungal, and cytomegalovirus infections. The primary outcome was graft failure, defined as the need for retransplantation or patient death. The secondary outcomes included the incidence of postoperative complications and infections. The follow-up period was extended until the earliest occurrence of graft loss, 5 years post-transplantation, or June 2024.

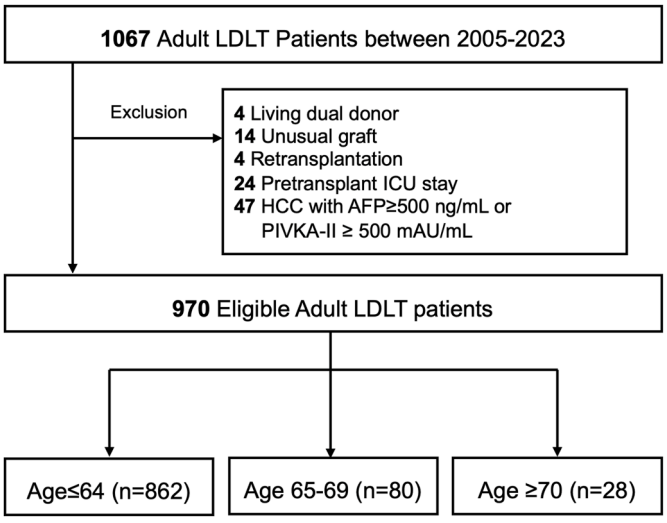

Fig. 1. Study flow
AFP, alpha fetoprotein; HCC, hepatocellular carcinoma; LDLT, living donor liver transplantation; PIVKA-II, Protein Induced by Vitamin K Absence or Antagonist-II.

2.3. Statistical analysis

Data are presented as mean ± standard deviation and median (interquartile range [IQR]) for continuous variables and as numbers (proportions) for categorical variables, where appropriate. The Mann–Whitney U, Kruskal–Wallis, and chi-square tests were employed to compare continuous and categorical variables, respectively, when appropriate. Kaplan–Meier analysis with the log-rank test was performed to compare graft survival among the groups. The independent association between age and graft survival was confirmed using univariate and multivariate Cox regression analyses.

To achieve a balanced comparison of baseline characteristics, the 65–69 and ≥ 70 age groups were matched to the ≤64 age group using propensity score (PS) matching at a 1:5 ratio. The nearest neighbor method with a caliper of 0.1 was employed for optimal matching accuracy. Additionally, PS was calculated through a comprehensive evaluation of all initial patient characteristics. Matching was considered adequate when the standardized mean differences (SMDs) for all baseline variables remained below 0.1.[19] Patients who could not be appropriately matched were excluded to preserve the validity of the analysis.

To identify key factors affecting graft survival in older LDLT recipients, subgroup survival comparisons by age were conducted, followed by multivariable analysis using the full model covariates. To ensure statistical relevance, these subgroup analyses were conducted by comparing recipients aged over 65 years with those under 65 years. All statistical analyses were performed using the R statistical package, version 4.4.1, for macOS (http://cran.r-project.org/), with the significance threshold set at $P < 0.05$.

2.4. Ethics approval

This study was conducted in accordance with the principles of the Declaration of Helsinki. The study was approved by the Institutional Review Board of Severance Hospital (4-2024-0447). Individual consent for this retrospective analysis was waived because of the retrospective design of the study.

3. Results

3.1. Baseline characteristics

As demonstrated in Table 1, the proportion of females was higher in older age groups (27.4 % in the ≤64 age group vs. 36.2 % in the 65–69 age group vs. 53.6 % in the ≥70 age group, P = 0.003). body mass index (BMI) was similar across the groups (23.8 [IQR 22.–25.9] vs. 24.0 [IQR 22.5–26.5] vs. 23.5 [IQR 21.6–25.8], P = 0.583). The years since transplantation were distributed unevenly, with an increased number of patients in the older age groups undergoing transplantation in recent years (P = 0.010). Hypertension was more frequent in older patients than in younger patients (22.3 % vs. 40.0 % vs. 32.1 %, P = 0.001)). Similarly, the incidence of diabetes mellitus (31.4 % vs. 40.0 % vs. 50.0 %, P = 0.041) and cardiovascular disease (7.5 % vs. 12.5 % vs. 17.9 %, P = 0.049) increased with age. Pre-transplant dialysis did not exhibit significant differences between the groups (P = 0.552). The ≥70 age group showed higher proportion of other underlying liver disease such as non-alcoholic steatohepatitis, toxic hepatitis, and cryptogenic liver disease. The prevalence of HCC was similar across the groups (50.1 % vs. 60.0 % vs. 50.0 %, P = 0.238). The MELD scores and in-hospital stays were comparable between the groups. The operation time was shorter in the older group than in the younger group (630 [IQR 540–720] min vs. 598 [IQR 502–694] min vs. 577 [IQR 505–703] min, P = 0.048). Cold ischemic time and red blood cell transfusion rates were similar (P = 0.615 and P = 0.194, respectively). Donor age increased with recipient age (30 [IQR 24–41] years vs. 38 [IQR 35–41] vs. 42 [IQR 39–44] years, P < 0.001), as did donor BMI (22.9 [21.0–24.8] vs. 23.3 [21.2–25.2] vs. 24.9 [IQR 22.3–25.8], P = 0.030). Donor sex, ABO incompatibility, and graft steatosis were not significantly different between the groups. In the matched cohorts, the groups demonstrated similar characteristics (Table S1 and S2).

As shown in Fig. S1, tacrolimus trough levels tended to be lower in older age groups compared to younger recipients throughout the first 180 days after LDLT. Additionally, older groups exhibited a trend toward less frequent use of mycophenolate mofetil beyond 90 days post-transplantation (Fig. S2).

3.2. Recipient age and survival

In an unmatched comparison, graft survival decreased with increasing recipient age: 91.0 %, 85.8 %, and 81.8 % in the ≤64 age group, compared to 83.7 %, 78.7 %, and 75.0 % in the 65–69 age group, and 82.0 %, 69.7 %, and 69.7 % in the ≥70 age group at 1, 3, and 5 years, respectively (P = 0.045, Fig. 2). However, graft survival in the 65–69 group and the ≥70 group was not statistically different from that in the ≤64 age group in matched analyses (78.9 % for ≤64 age group vs. 74.5 % for 65–69 age group, P = 0.324; 80.3 % for ≤64 age group vs. 76.0 %, P = 0.551 for ≥70 age group, Fig. 3). In multivariable Cox analysis, neither the 65–69 (hazard ratio [HR] 1.44, 95 % confidence interval [CI] 0.87–2.37) nor the ≥70 age group (HR 1.69, 95 % CI 0.82–3.49) demonstrated an increase in the risk of graft failure compared to that noted in the ≤64 age group (Table 2, full results in Table S3). Among the patients who died, infection was the most common cause of death in all groups; however, the proportion was significantly high in the older

Table 1
Baseline characteristics.

	Age≤64 (n = 862)	Age 65–69 (n = 80)	Age≥70 (n = 28)	*P*
Age	54 (49–59)	66 (65–67)	72 (71–72)	<0.001
Sex, female	236 (27.4)	29 (36.2)	15 (53.6)	0.003
BMI, kg/m^2	23.8 (22.0–25.9)	24.0 (22.5–26.5)	23.5 (21.6–25.8)	0.583
Year of transplantation				0.010
2012–2015	246 (28.5)	13 (16.2)	3 (10.7)	
2016–2018	242 (28.1)	22 (27.5)	6 (21.4)	
2019–2022	374 (43.4)	45 (56.2)	19 (67.9)	
Hypertension	192 (22.3)	32 (40.0)	9 (32.1)	0.001
Diabetes mellitus	271 (31.4)	32 (40.0)	14 (50.0)	0.041
Cardiovascular disease	65 (7.5)	10 (12.5)	5 (17.9)	0.049
Pretransplant dialysis	35 (4.1)	2 (2.5)	2 (7.1)	0.552
Underlying liver disease				<0.001
Hepatitis B	484 (56.1)	36 (45.0)	8 (28.6)	
Hepatitis C	42 (4.9)	7 (8.8)	3 (10.7)	
Alcoholic	200 (23.2)	21 (26.2)	3 (10.7)	
Autoimmune liver disease	44 (5.1)	6 (7.5)	2 (7.1)	
Acute liver failure	14 (1.6)	1 (1.2)	1 (3.6)	
Others	78 (9.0)	9 (11.2)	11 (39.3)	
Hepatocellular carcinoma	432 (50.1)	48 (60.0)	14 (50.0)	0.238
Pretransplant MELD				0.472
6-10	335 (38.9)	28 (35.0)	7 (25.0)	
11-20	364 (42.2)	41 (51.2)	16 (57.1)	
21-30	113 (13.1)	7 (8.8)	3 (10.7)	
31-40	50 (5.8)	4 (5.0)	2 (7.1)	
Pretransplant in-hospital stay	278 (32.3)	28 (35.0)	10 (35.7)	0.826
Operation time, min	630 (540–720)	598 (502–694)	577 (505–703)	0.048
Cold ischemic time, min	127 (102–155)	130 (103–160)	135 (109–162)	0.615
Warm ischemic time, min	50 (38–63)	49 (39–56)	19 (41–71)	0.622
RBC transfusion, pack	3 (1–7)	4 (2–7)	4 (2–8)	0.194
Donor age	30 (24–41)	38 (35–41)	42 (39–44)	<0.001
Donor sex, female	349 (40.5)	34 (42.5)	7 (25.0)	0.235
Donor BMI, kg/m^2	22.9 (21.0–24.8)	23.3 (21.2–25.2)	24.9 (22.3–25.8)	0.030
ABO incompatibility	181 (21.0)	22 (27.5)	7 (25.0)	0.365
GRWR<0.8	51 (5.9)	2 (2.5)	3 (10.7)	0.239
Graft steatosis>10 %	121 (14.0)	10 (12.5)	4 (14.3)	0.929

Data are presented as number (percentage) or median (interquartile range).
BMI, body mass index; GRWR, graft to recipient weight ratio; MELD, model for end-stage liver disease; RBC, red blood cell.

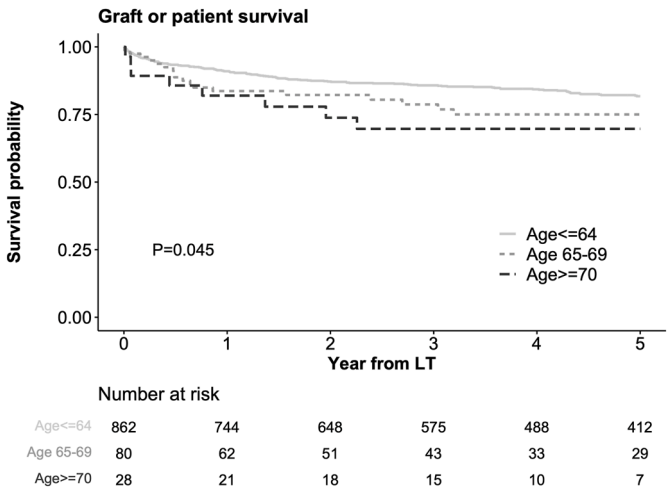

Fig. 2. Graft or patient survival between age groups.

age groups (29.9 % vs. 50.0 % vs. 42.9 %, Fig. 4).

3.3. Postoperative course and complications

As demonstrated in Table 3, in-hospital mortality rates displayed an increasing trend with age but did not reach statistical significance (4.9 % in the ≤64 age group vs. 5.0 % in the 65–69 age group vs. 10.7 % in the ≥70 age group, P = 0.381). Furthermore, ICU stays post-LT were comparable across age groups (4 [IQR 3–5] days in each group, P = 0.152), as were overall hospital stays (23 [IQR 18–33] days vs. 23 [IQR 18–34] vs. 24 [IQR 20–37], P = 0.828). Readmission within 180 days also revealed no significant differences among the age groups (60.0 % vs. 53.8 % vs. 57.1 %, P = 0.539).

For postoperative outcomes within 1 year, the rejection incidence was similar between the groups (26.8 % vs. 30.4 % vs. 22.8 %, P = 0.644). The total vascular complications (6.4 % vs. 9.1 % vs. 14.4 %, P = 0.147) were not statistically different between the groups. In addition, bile leak (14.7 % vs. 16.6 % vs. 15.8 %, P = 0.874) and bile duct strictures (33.8 % vs. 37.4 % vs. 30.0 %, P = 0.528) were

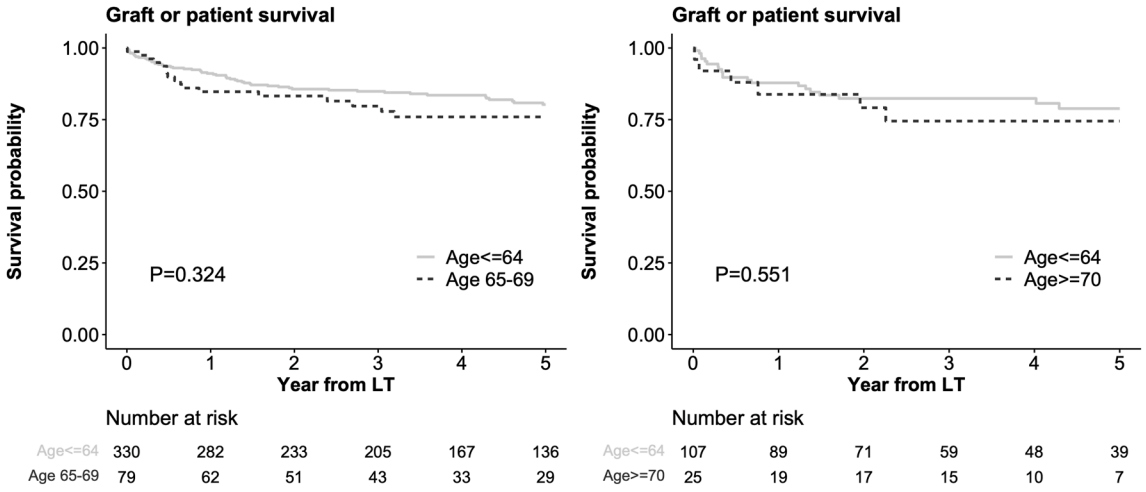

Fig. 3. Survival comparison between matched groups
(a) matched cohort between Age≤64 and Age 65–69, (b) matched cohort between Age≤64 and Age≥70.

Table 2
Uni- and Multivariable Cox for graft or patient survival.

Variables	Univariable		Multivariable[a]	
	HR (95 % CI)	*P*	HR (95 % CI)	*P*
Age group, vs. Age≤64 years				
Age 65–69 years	1.51 (0.93–2.47)	0.099	1.44 (0.87–2.37)	0.156
Age≥70 years	2.03 (1.00–4.14)	0.052	1.69 (0.82–3.49)	0.156
BMI, kg/m^2	0.94 (0.89–0.98)	0.008	0.93 (0.89–0.98)	0.005
Diabetes mellitus	1.34 (0.98–1.83)	0.069	1.29 (0.93–1.77)	0.124
Cardiovascular disease	1.97 (1.26–3.09)	0.003	1.90 (1.20–3.00)	0.006
Pretransplant dialysis	2.19 (1.22–3.95)	0.009	1.57 (0.84–2.96)	0.161
Pretransplant MELD	1.02 (1.00–1.04)	0.062	1.00 (0.98–1.03)	0.808
Pretransplant in-hospital stay	1.46 (1.07–1.99)	0.018	1.38 (0.98–1.95)	0.068
Operation time, per 60min	1.08 (1.02–1.15)	0.01	1.04 (0.97–1.12)	0.3
CIT, per 30min	1.10 (1.00–1.21)	0.043	1.07 (0.96–1.18)	0.216
RBC transfusion, pack	1.03 (1.02–1.04)	<0.001	1.02 (1.01–1.04)	<0.001
Donor age, per 10 years	1.23 (1.09–1.40)	0.001	1.23 (1.07–1.40)	0.002

Only variables of which P value < 0.1 in univariable analysis were presented.
Full results are provided in the Table S3
AST, aspartate aminotransferase; BMI, body mass index; HCC, hepatocellular carcinoma; LT, liver transplantation; MELD, model for end-stage liver disease; POD, postoperative day.

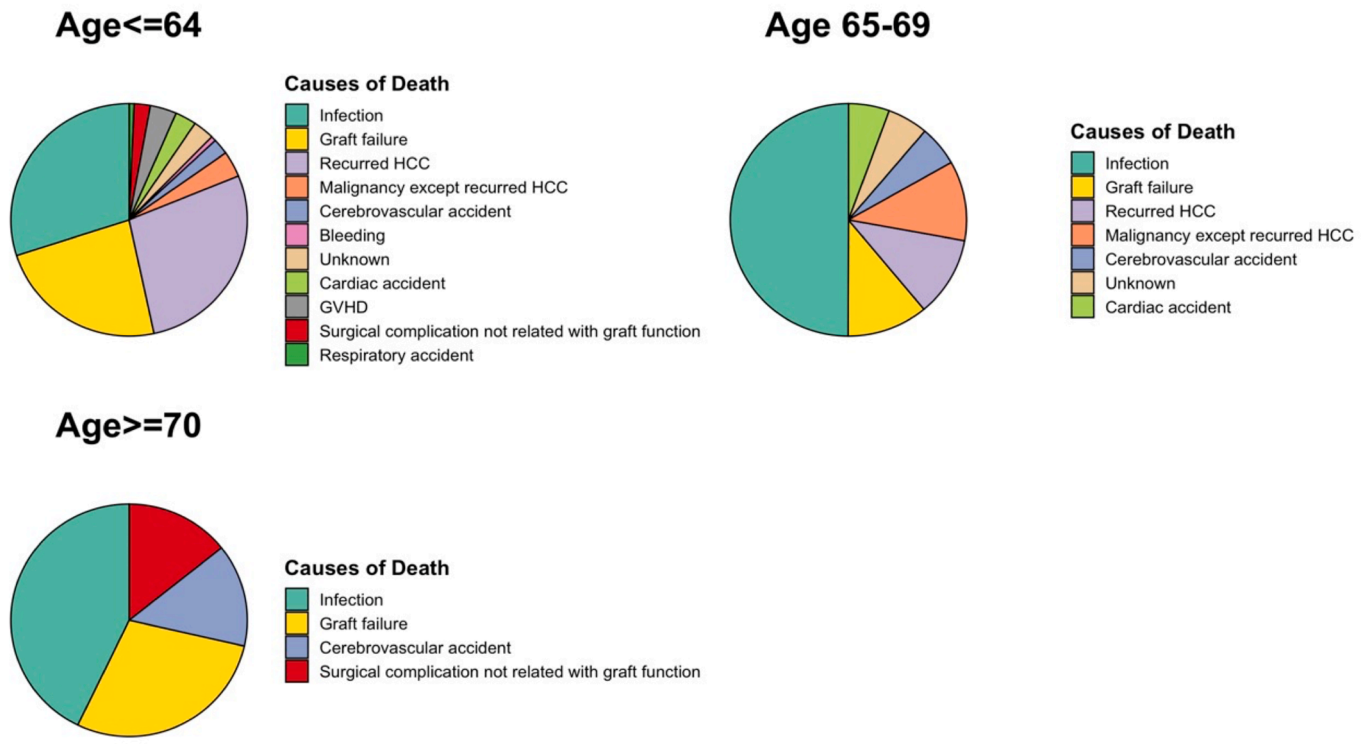

Fig. 4. Causes of death
GVHD, graft-versus-host disease; HCC, hepatocellular carcinoma.

Table 3
Post-operative outcomes.

	Age≤64 (n = 862)	Age 65–69 (n = 80)	Age≥70 (n = 28)	*P*
In-hospital mortality	42 (4.9)	4 (5.0)	3 (10.7)	0.381
Post-LT ICU stay, days	4 (3–5)	4 (3–5)	4 (3–5)	0.152
Hospital stay, days	23 (18–33)	23 (18–34)	24 (20–37)	0.828
Readmission within 180 days	517 (60.0)	43 (53.8)	16 (57.1)	0.539
Complications within 1 year[a]				
Rejection	226 (26.8)	24 (30.4)	6 (22.8)	0.644
Total vascular complication	53 (6.4)	7 (9.1)	4 (14.4)	0.147
Bile leak	123 (14.7)	13 (16.6)	4 (15.8)	0.874
Bile duct stricture	277 (33.8)	29 (37.4)	7 (30.0)	0.528
Infection within 1 year[a]				
Bacteremia	233 (27.5)	29 (36.7)	8 (28.9)	0.207
Fungemia	36 (4.4)	3 (4.1)	0	0.571
Pneumonia	93 (11.3)	16 (20.8)	5 (19.3)	0.019
CMV infection	137 (16.4)	13 (16.9)	8 (30.2)	0.149

CMV, cytomegalovirus; ICU, intensive care unit.
[a] Complications and infection within 1 year were estimates by Kaplan-Meier curves, which were compared with log rank test.

also not significantly different between groups.

Among infections within 1 year, pneumonia was significantly more common in the older group than in the younger one (11.3 % vs. 20.8 % vs. 19.3 %, P = 0.019). Bacteremia (27.5 % vs. 36.7 % vs. 28.9 %, P = 0.207) and fungemia (4.4 % vs. 4.1 % vs. 0 %, P = 0.571, P = 0.571) were not statistically significant across the age groups. The cytomegalovirus infection rate was also similar between the groups, although the rate was slightly higher in the ≥70 age group (16.4 % vs. 16.9 % vs. 30.2 %, P = 0.149).

4. Subgroup analyses for risk factors of LDLT in older patients

When the older group was defined as ≥65 years, older age was associated with an increased risk of graft loss in patients with MELD scores ≥20 (aHR 2.97, 95 % CI 1.25–7.08, Table S4), but not in those with MELD <20 (aHR 1.14, 95 % CI 0.68–1.88). Older age was also a significant risk factor only in subgroups with diabetes mellitus (aHR 2.28, 95 % CI 1.25–4.16) and when the donor BMI was ≥23 kg/m^2 (aHR 1.95, 95 % CI 1.12–3.40).

5. Discussion

Our analysis demonstrated that older recipients aged 65–69 and even more than 70 years had graft survival rates comparable to those of younger patients despite a high prevalence of preexisting conditions such as hypertension and diabetes. However, the incidence of infectious complications, particularly pneumonia, was notably high in the older age group, emphasizing the importance of infection control. These results enhance our

understanding of LDLT in older populations and demonstrate that LDLT can be a viable option for the careful management of older patients.

In LDLT, the mental health of live donors can be influenced by recipient outcomes, making it essential to maximize these outcomes, provided that the donor safety is not compromised.[20,21] From this perspective, candidate selection is particularly important in older patients who typically present with more comorbidities than do younger recipients.[22] Consistent with this expectation, our study identified that the older group had a high prevalence of underlying conditions; as a result, graft survival was low among older patients in the unmatched analysis. However, in the matched analysis, both the 65–69 and ≥ 70 age groups exhibited graft survival comparable to that of the younger group. Thus, when considering LDLT in older patients, careful assessment of extrahepatic comorbidities is crucial for optimizing outcomes.

The benefits of LDLT can vary depending on the regional deceased donor pool and the expected waitlist mortality. Analysis using UNOS data has demonstrated that patients with a MELD score of 11 or higher derive a survival benefit from LDLT.[23] In Asian countries, where organ shortages are more severe than in the West, significant survival gains from LDLT have been observed, even with high MELD scores of 25–30.[24–26] For older patients who generally have lower physiological reserves than those in younger recipients, waitlist mortality is naturally higher for the same severity of liver disease.[10] Furthermore, even if older patients receive DDLT, disease progression while on the waitlist may result in poor post-transplantation outcomes.[27] In contrast to the UNOS data, which reports survival rates of 68 % for 65–69-year-olds and 62 % for those over 70, our study identified higher survival rates of 75 % in the 65–69 age group and 69 % in the over 70 age group.[10] These findings suggest that for older patients with end-stage liver disease, LDLT can offer timely management with potentially great survival benefits. However, further comparative analyses of waitlisted patients are necessary to confirm this advantage.

In LDLT, the risk of surgical complications, including bile duct complications, is generally higher than that in DDLT, raising concerns that these risks could be elevated in older patients.[28,29] However, existing studies indicate that complication rates in older LDLT recipients are not significantly higher than those in younger recipients.[11,13,14,16,20] Even in studies reporting reduced overall survival in older LDLT patients, the rates of surgical complications have not been demonstrated to increase with age.[17] Our findings align with these observations, as we discovered no significant differences in vascular complications, bile leaks, or biliary strictures across the age groups. In addition, surgical complications are closely associated with living donor selection criteria such as GRWR.[30] As we previously demonstrated using multicenter data, LDLT with a small graft size may pose greater risks in older recipients; however, this could not be adequately analyzed in the present single-center dataset. Although the current evidence suggests that the risk of surgical complications should not be a primary concern when considering LDLT in older patients, further analysis in large cohorts is warranted to confirm these findings.

One of the primary concerns in older LDLT patients is the possibility that immunosenescence due to aging may reduce rejection rates but increase susceptibility to infection.[22] To date, no comparative analyses of infection and rejection have been reported, specifically in older patients undergoing LDLT. To the best of our knowledge, the study by Avanaz et al., which revealed high sepsis-related mortality in LDLT recipients aged >65 years, is the only such report.[11] In DDLT, a meta-analysis indicated no significant differences in major infection rates according to recipient age, although this finding may be limited by heterogeneity in age definitions and study populations.[7] Our study demonstrated no difference in rejection rates, but a high incidence of pneumonia in older LDLT groups. Additionally, among deceased patients, infectious mortality was more prevalent in older cohorts than in younger ones. Further analysis using large-scale data is essential to confirm and expand these findings.

Similar to previous studies, this study was limited by the small sample size of older age groups and the use of single-center data, so that implication of important factors such as graft donor selection in older recipients could not be analyzed. In addition, owing to the retrospective nature of the study, we could not confirm the effect of individualized immunosuppression, which could act as a critical intervention for LT outcomes in older patients. Lastly, no data on sarcopenia or the performance status of older recipients was available, which could affect confounders in the survival analyses.

In conclusion, LDLT in patients aged 65–69 years and >70 years demonstrated survival rates comparable to those in younger patients when adjusted for underlying comorbidities. The increased incidence of pneumonia in the older groups underscores the importance of targeted infection prevention strategies to enhance postoperative outcomes in older LT recipients.

Author contributions

D.J.J. had full access to all aspects of the study and takes responsibility for the integrity of the data and the accuracy of the data analysis;

D.-G.K. and D.J.J. participated in the research design;

E.-K.M., J.G.L., D.J.J. and M.S.K. participated in the performance of the research;

D.-G.K, Y.J.Y., M.K., H.-H.K, E.-K.M. and participated in the data acquisition;

D.-G.K, Y.J.Y., H.-H.K and D.-G.K. participated in the statistical analysis;

D.-G.K. Participated in the writing of the paper;

D.J.J. supervised the study process. All authors have read and agreed to the published version of the manuscript.

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None.

Declaration of competing interest

The authors declare no conflicts of interest.

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None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asjsur.2025.08.303.

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