

IMPACT OF SURGERY TIMING ON OUTCOMES FOLLOWING LIVER TRANSPLANTATION: A RETROSPECTIVE POPULATION-BASED STUDY

Maximilian Trog^{1*}, Svenja Sliwinski^{1*}, Faruk Koca¹, Peter Dancs¹, Ekaterina Petrova¹, Philip Baum², Johannes Diers³, Armin Wiegeling^{1,4,5}, Tamas Benkö^{1**}, Konstantin Uttinger^{1,4,5**}

¹ Goethe University Frankfurt, University Hospital, Department of General, Visceral, Transplant and Thoracic Surgery, Germany; ² Department of Thoracic Surgery, Thoraxklinik at Heidelberg University Hospital, Röntgenstraße 1, Heidelberg, Germany; ³ Marienkrankenhaus Hamburg, Germany; ⁴ Frankfurt Cancer Institute, Georg-Speyer-Haus, Frankfurt am Main, Germany; ⁵ University Cancer Center Frankfurt (UCT), Frankfurt University Hospital, Goethe University, Frankfurt am Main, Germany

* Shared first; ** Shared last

Summary

Objective. Liver transplantation is a non-elective procedure. While nocturnal surgery has been associated with worse outcomes, evidence in transplantation remains inconsistent. This study intends to provide nationwide data from Germany with a MELD-based allocation system and donation after brain death.

Methods. This is a retrospective population-based study using billing data of patients undergoing liver transplantation between 2012 and 2023. Surgical timing was categorized as nighttime (00:00-05:59), routine hours (06:00-16:59), and evening (17:00-23:59). Primary outcomes were in-hospital mortality and failure to rescue. Secondary outcomes included a composite endpoint (prolonged length of stay, relaparotomy, re-transplantation, or death).

Results. Among 8,492 recipients (median age 56 years; 34.0% female), 18.7% of procedures occurred at night and 27.5% on weekends. In-hospital mortality was 12.6%, with no variation across time-of-day categories. Nighttime transplantation was not associated with increased mortality. Routine-hour procedures were associated with a lower risk of the composite endpoint compared with evening surgery (OR 0.83, 95% CI 0.72-0.96). Mortality was driven by age, comorbidity burden, and acute liver failure. Weekend transplantation was not associated with excess risk.

Conclusions. In this nationwide cohort, surgical timing was not associated with adverse short-term outcomes after liver transplantation. Patient-related factors, rather than procedural timing, were the principal determinants of in-hospital mortality.

Keywords: liver transplantation, daytime of surgery, weekday of surgery, safety of surgery, secondary data analysis, real world analysis

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Correspondence

Konstantin Uttinger

E-mail: konstantin.uttinger@unimedizin-
ffm.de

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INTRODUCTION

Liver transplantation is among the most time-critical and complex procedures

in visceral surgery. Because the timing of organ availability is largely unpredictable, operations are frequently performed during nighttime hours. Current evidence indicates that procedures conducted at night are associated with higher complication rates compared to those performed during the day, a phenomenon partly attributed to increased handover frequency and e.g. higher transfusion requirements, resulting in elevated morbidity and mortality rates^{1,2}.

For solid organ transplantation, however, the evidence is less consistent. Studies on kidney transplantation consistently demonstrate that the timing of surgery – whether day versus night or weekday versus weekend – does not significantly influence patient or graft survival. Large retrospective analyses and meta-analyses report no clinically relevant differences in outcomes such as patient survival, graft loss, or surgical complications^{3,4}.

Regarding liver transplantation, most registry-based studies from the United Kingdom and the United States likewise indicate no significant association between time of day or day of the week and key outcomes such as patient or graft survival^{5,6}. German single-center studies report similar findings, showing no increase in one-year patient or graft mortality following weekend or nighttime transplantation^{7,8}. However, these German data are derived from smaller cohorts and differ from UK and US settings in important aspects. In particular, the German organ allocation system is primarily MELD-driven and relies exclusively on donation after brain death (DBD), creating distinct clinical and logistical conditions.

To address the current lack of large, nationwide data from Germany, we conducted a retrospective analysis using secondary billing data to examine whether liver transplantation performed during nighttime hours or on weekends is associated with increased risks of patient or graft complications.

METHODS

This is a retrospective, population-based cohort study utilizing anonymized billing data provided by the Federal Statistical Office in Germany. All billing records from hospital admissions in Germany are registered annually with the Federal Statistical Office in Germany. The data source includes the RDC of the Federal Statistical Office and Statistical Offices of the Federal States (DOI: 10.21242/23141.2012.00.00.6.1.0-10.21242/23141.2023.00.00.6.1.0 and 10.21242/23141.2019.00.00.6.1.1, own calculations). Data were acquired and analyzed in collaboration with the Federal Statistical Office, adhering to their guidelines for handling highly sensitive patient data. No ethical approval was required for this anonymized nationwide cohort analysis.

Study population

Patients for this analysis were identified using coding according to the International Classification of Diseases, ICD coding, and OPS, "Operationen und Prozedurenschlüssel", procedural coding. All adult patient records with a coded liver transplantation (OPS 5-504) between January 1, 2012, and December 31, 2023 were included (Supp. Table I, Supp. Figure 1). In case of duplicates based on all available variables, one record was randomly kept for further analysis. Each patient record contained data on age, sex, an institute identifier, procedural codes including linked date and time variables, primary and secondary diagnoses, length of stay, and reasons for admission and discharge. Only the index hospitalization was available for all analyses; no patient identifier was available, precluding the identification of readmissions. Different sub-cohorts were pre-specified to be analyzed separately: the total cohort and sub-cohorts based on the coded main liver disease (alcohol associated liver disease, primary sclerosing cholangitis or primary biliary cholangitis, hepatocellular carcinoma, acute liver failure, and others).

Timing of liver transplantation

There is a linked time and date variable with a specific affiliation to each individual OPS code. These time variables reflect the beginning of the OPS procedure as specified in the billing data process (according to § 21 KHEntgG, German "Krankenhausentgeltgesetz"). It is not verifiable if this, in the case of liver transplantation, is the time of preparations (i.e. protocolling in the operating room) or the time of the actual beginning of the surgery, as coding varies among hospitals. Time of surgery was grouped as 0.00 am through 5.59 am, 6.00 am through 4.59 pm, and 5.00 pm through 11.59 pm to reflect the relevant grouping to "after midnight during off-hours", "during routine hours", "after routine hours before midnight".

Primary and secondary outcome measures

The primary outcome measures of this analysis were in-hospital mortality, and failure to rescue, i.e. mortality in the presence of a coded complication. The list of complications in this analysis was based on available complication coding within the DRG data, i.e. "diagnosis related groups", and on clinical relevance (Supp. Table I). Secondary outcome measures were complication occurrence and a combined clinical endpoint, defined as length of stay longer than the 75th percentile in the corresponding age group and diagnosis group, relaparotomy, re-liver-transplantation, and or death. All outcome measures were pre-defined to be analyzed by weekday of surgery, in which case weekend surgeries were defined to be analyzed as one group, and by time of surgery.

Statistical analysis

Odd's ratios (OR) were calculated between independent variables and the primary outcome measure "in-hospital mortality" and the combined endpoint as secondary outcome measure. In a multivariable logistic regression model, the relationships between dependent and the outcome measures were determined. Relevant available covariates were adjusted for in the multivariable models (age, sex, Charlson comorbidity index, main diagnosis of liver disease). In all multivariable models, the standard error was adjusted for the treating hospital to account for clustering. Likelihood ratio tests were used to assess logistic regression model accuracy. We excluded the presence of significant multicollinearities among confounding variables. For the logistic regression model, age categories were maintained for interpretation purposes. To obtain a comorbidity index, the Charlson comorbidity index⁹ was used based on the Stata plugin "charlson icd_sidediagnoses". The work has been reported according to the STROBE guidelines¹⁰. Graphs were generated using Graphpad Prism (Version 10). Stata (Version 19; Stata-Corp LP, Texas, USA) was used for all statistical analyses.

RESULTS

Patient characteristics

A total of 8,492 patients met the inclusion criteria (Supp. Table 1, Supp. Figure 1). The most common main diagnoses of the liver disease were other liver diseases (3,445, 40.6%), alcohol-associated liver disease (1,826, 21.5%), and hepatocellular carcinoma (1,609, 18.9%). Primary sclerosing cholangitis (PSC) and primary biliary cholangitis (PBC) accounted for 10.4% of cases (883), while acute liver failure was coded in 8.6% (729). The median age of the overall cohort was 56 years (interquartile range, IQR, 47-62). Patients with hepatocellular carcinoma were the oldest subcohort (median age 61 years, IQR 56-65), whereas those with PSC/PBC (median: 48 years, IQR 39-57) and acute liver failure (median: 49 years, IQR 37-58) were the youngest. Overall, 34% (2,887) of transplant recipients were female. The proportion of women was highest among patients with acute liver failure (422, 57.9%) and lowest in alcohol-associated liver disease (412, 22.6%) and in hepatocellular carcinoma (317, 19.7%). 67.3% of patients had a Charlson comorbidity index of two or higher (2: 2,759, 32.5%, 3: 2,957, 34.8%). Higher comorbidity scores were most common among patients with alcohol-associated liver disease (CCI 3 829, 45.4%) and least common among PBC/PSC patients (CCI 3 181, 20.5%). The median length of stay was 31 days (IQR 20-56), ranging from 22 days in patients with hepatocellular

carcinoma (IQR 17-33) to 41 days in those with acute liver failure (IQR 27-62) (Tab. I). CHILD Scores were unknown in 77.5% (6,578) of cases due to non-standardized coding (Supp. Table II). Comorbidities are listed in detail in Supp. Table II).

Daytime of surgery

Most transplantations were performed during daytime hours between 6:00 am and 4:59 pm (4,957, 58.4%), while 23.0% (1,951) occurred in the evening (5:00 pm-11:59 pm) and 18.7% (1,584) during the night (0:00-5:59 am). Overall, any complication occurred in 68.8% (5,845) of patients, with no relevant variation across time intervals. The overall failure-to-rescue rate was 18% (1,053) and was consistent across surgical time periods (0:00-4:59 pm: 799, 17.8%; 5:00 pm-11:59 pm: 254, 18.7%). The combined endpoint (length of stay longer than 75th percentile in age group and diagnosis group, relaparotomy, re-liver-transplantation, death) occurred in 37.9% (3,215) of cases, with slightly higher rates observed in evening procedures (760, 39%) compared to nighttime operations (560, 35.4%). In-hospital mortality was 12.6% (1,068) overall and ranged between 12.1% (191) at night and 13.2% (257) in the evening. The other components of the combined endpoint — prolonged length of stay, relaparotomy and re-liver-transplantation — were similarly distributed across time intervals (Tab. II). The distribution of the main liver disease by daytime of surgery is provided in detail in Supp. Table III).

Weekday of surgery

The highest proportion of liver transplantations was performed on weekends (27.5%, 2,335), followed by Wednesday (17.1%, 1,453) and Thursday (16.4%, 1,396) and the lowest proportion on Monday (9.3%, 786). Complication rates were comparable across weekdays, ranging between 67.2% (528) on Monday and 69.9% (845) on Tuesday. Failure-to-rescue rates were highest following Monday transplantation surgery (21.2%, 112) and lowest following Friday surgeries (15%, 134). The combined endpoint occurred in 37.9% of patients overall, with lower rates toward the end of the week (Friday 35.3%, 463) and on weekends (36.9%, 861) compared with earlier weekdays (Monday: 39.3%, 309, Tuesday: 39.9%, 483). In-hospital mortality was highest following Monday transplantations (14.8%, 116) and lowest following Friday surgeries (10.4%, 136), while in-hospital mortality following weekend surgeries was 12.9% (301). Relaparotomy was the most frequent individual component of the combined endpoint (approximately 30% of patients) and demonstrated minor variation across weekdays, i.e. lowest Friday (28.4%, 373) and highest Tuesday (32.3%, 390). Re-transplantation rates ranged between 4.5% and 6.6% without a clear weekday pattern (Tab. III). The distribution of the main

Table I. Patient characteristics.

	Overall	Alcohol-associated LD	PSC or PBC	Hepatocellular carcinoma	Acute LF	Other
Total no. of patients n (%)	8,492	1,826 (21.5)	883 (10.4)	1,609 (18.9)	729 (8.6)	3,445 (40.6)
Age (years; median, IQR)	56 (47-62)	57 (52-62)	48 (39-57)	61 (56-65)	49 (37-58)	54 (45-61)
≤ 49	2,537 (29.9)	303 (16.6)	478 (54.1)	153 (9.5)	376 (51.6)	1,227 (35.6)
50-59	3,003 (35.4)	828 (45.4)	246 (27.9)	529 (32.9)	198 (27.2)	1,202 (34.9)
≥ 60	2,952 (34.8)	695 (38.1)	159 (18)	927 (57.6)	155 (21.3)	1,016 (29.5)
No. of females n (%)	2,887 (34)	412 (22.6)	357 (40.4)	317 (19.7)	422 (57.9)	1,379 (40)
Charlson comorbidity index # n (%) 0	581 (6.8)	72 (3.9)	120 (13.6)	43 (2.7)	140 (19.2)	206 (6)
1	2,195 (25.9)	264 (14.5)	314 (35.6)	658 (40.9)	204 (28)	755 (21.9)
2	2,759 (32.5)	661 (36.2)	268 (30.4)	411 (25.5)	212 (29.1)	1,207 (35)
3	2,957 (34.8)	829 (45.4)	181 (20.5)	497 (30.9)	173 (23.7)	1,277 (37.1)
Length of stay (days)*	31 (20-56)	33 (20-62)	27 (19-50)	22 (17-33)	41 (27-62)	35 (21-63)

LD: liver disease; LF: liver failure. Values in parentheses are percentages of the total in the patient group unless otherwise indicated. #: The Charlson comorbidity index was obtained using the STATA plugin "charlson icd_sidediagnoses, index(10)". 0: 0 points; 1: 1-2 points; 2: 3-4 points; 3: > 4 points.

Table II. Liver transplantation by time of surgery: combined endpoint.

	Overall	0.00 am – 5.59 am	6.00 am – 4.59 pm	5 pm – 11.59 pm
Total no. of patients n (%)	8,492	1,584 (18.7)	4,957 (58.4)	1,951 (23)
Any complication occurrence n (%)	5,845 (68.8)	1,071 (67.6)	3,414 (68.9)	1,360 (69.7)
Failure to rescue n (%)	1,053 (18)	191 (17.8)	608 (17.8)	254 (18.7)
Overall occurrence of combined endpoint (LOS > 75th percentile age group and diagnosis group, Relaparotomy, Re-liver-transplantation, death) n (%)	3,215 (37.9)	560 (35.4)	1,895 (38.2)	760 (39)
In-hospital mortality	1,068 (12.6)	191 (12.1)	620 (12.5)	257 (13.2)
LOS > 75th percentile age group and diagnosis group	536 (6.3)	80 (5.1)	318 (6.4)	138 (7.1)
Relaparotomy	2,523 (29.7)	445 (28.1)	1,482 (29.9)	596 (30.6)
Re-Liver-transplantation	473 (5.6)	84 (5.3)	286 (5.8)	103 (5.3)

Values in parentheses are percentages of the total in the patient group unless otherwise indicated. LOS: length of stay.

liver disease by weekday of surgery is provided in detail in Supp. Table III).

Multivariable logistic regression model results

A multivariable logistic regression model adjusted for variation among covariates for a primary outcome measure, i.e. in-hospital mortality, and a secondary outcome measure, i.e. a combined clinical endpoint. Occurrence of primary and secondary outcome measures by main liver disease are listed in Supp. Table IV, and individual complications are listed in Supp. Table V.

Risk of occurrence of the combined clinical endpoint increased with the Charlson Comorbidity index (Odd's

Ratio, OR, for CCI group 3: 2.19, 95% confidence interval, CI, 1.79-2.68; group 0 as reference) and was highest in acute liver failure (acute liver failure as reference; hepatocellular carcinoma: OR 0.35, CI 0.29-0.43). In reference to evening surgeries (5:00 pm-11:59 pm), morning surgeries were associated with a reduced risk (OR 0.83, CI 0.72-0.96, $p=0.014$). There was no risk difference by weekday of surgery (Fig. 1, Supp. Table VI).

Risk of in-hospital death increased with age (≤ 49 years as reference: ≥ 60 years OR 1.42, CI 1.20-1.69), increased with the Charlson Comorbidity index (CCI group 3: OR 2.10, CI 1.41-3.15), and was highest in acute liver failure (acute liver failure as reference; hepatocellular carcinoma: OR

Table III Liver transplantation by weekday of surgery: combined endpoint.

	Mo	Tue	Wed	Thur	Fri	Weekend
Number of patient records (8,492)	786 (9.3)	1,209 (14.2)	1,453 (17.1)	1,396 (16.4)	1,313 (15.5)	2,335 (27.5)
Any complication occurrence n (%), overall 5,845 (68.8%)	528 (67.2)	845 (69.9)	994 (68.4)	966 (69.2)	892 (67.9)	1,620 (69.4)
Failure to rescue n (%), overall 1,053 (18%)	112 (21.2)	163 (19.3)	172 (17.3)	174 (18)	134 (15)	298 (18.4)
Overall occurrence of combined endpoint (LOS > 75th percentile age group and diagnosis group, Relaparotomy, Re-liver-transplantation, death) n (%), overall 3,215 (37.9%)	309 (39.3)	482 (39.9)	565 (38.9)	535 (38.3)	463 (35.3)	861 (36.9)
In-hospital mortality (1,068, 12.6%)	116 (14.8)	165 (13.7)	175 (12)	175 (12.5)	136 (10.4)	301 (12.9)
LOS > 75th percentile age group and diagnosis group, overall 536 (6.3%)	54 (6.9)	78 (6.5)	111 (7.6)	97 (7)	70 (5.3)	126 (5.4)
Relaparotomy, overall 2,523 (29.7%)	234 (29.8)	390 (32.3)	430 (29.6)	418 (29.9)	373 (28.4)	678 (29)
Re-Liver-transplantation, overall 473 (5.6%)	48 (6.1)	80 (6.6)	65 (4.5)	75 (5.4)	72 (5.5)	133 (5.7)

Values in parentheses are percentages of the total in the patient group unless otherwise indicated. LOS: length of stay.

0.26, CI 0.18-0.39). There was no risk difference by day-time of surgery. In reference to Monday liver transplantations, performance on Wednesdays (OR 0.78, CI 0.65-0.94, $p=0.007$) and Fridays (OR 0.67, CI 0.52-0.85, $p=0.001$) were associated with reduced risk of death (Figure 1, Supp. Table VII).

DISCUSSION

In this nationwide, population-based cohort study we conducted an analysis of more than 8,400 liver transplantations undertaken in Germany over a 12-year period.

There was no clinically relevant association between the timing of surgery, especially time of day or weekday, and in-hospital mortality. Moreover, failure to rescue or morbidity in general was not associated with day or nighttime surgery. Also, after adjusting for patient-related risk factors, such as age and comorbidity, these results remained applicable. Despite findings of an association between nighttime surgery and adverse outcomes with regards to other surgical disciplines, this data suggests that liver transplantation is an exception^{1,2}. Our data show that in-hospital mortality or failure to rescue remain the same with regards to nighttime or weekend liver transplant surgery. The absence of such a nighttime or weekend effect persisted in our conducted multivariable models, after accounting for grouping of the main liver disease and comorbidity burden – factors relevant in transplant patients.

The only significant differences were seen when explicitly looking at specific weekdays. We observed a lower

adjusted in-hospital mortality following Wednesday and Friday surgeries. This is most plausibly explained by residual confounding rather than a protective weekday effect and should not be overinterpreted. It was not the primary purpose of this analysis to analyze effects with regards to secondary timing, e.g. relaparotomy performance on weekends; weekday effects might be associated with timing of complication occurrence, yet this was not analyzed further. Evaluation of the combined endpoint according to weekday showed no significant differences. Therefore, weekend transplantations and nighttime transplantations were not associated with inferior outcomes, supporting the hypothesis that transplantation services in Germany provide consistent quality of care across the entire week. These findings align with previous analyses from the US and the UK, which similarly reported no detrimental effect of nighttime or weekend liver transplantation on patient or graft survival¹¹. Other studies, limited by single-center designs and therefore with substantially smaller sample sizes, reached comparable conclusions^{7,8}. Our present analysis extends this evidence by providing, to our knowledge, the first nationwide evaluation of timing effects in liver transplantation in the German healthcare system over a long period of time, while a similar UK analysis came to the same conclusion⁵. In contrast, there exists data for kidney transplantation, where selected high-risk subgroups have been reported to experience worse outcomes following weekend surgery¹². Our data do not indicate a comparable vulnerability in liver transplant recipients and the discrepancy may reflect underlying differences in perioperative complexity, team composition and institutional preparedness. In Germany, liver

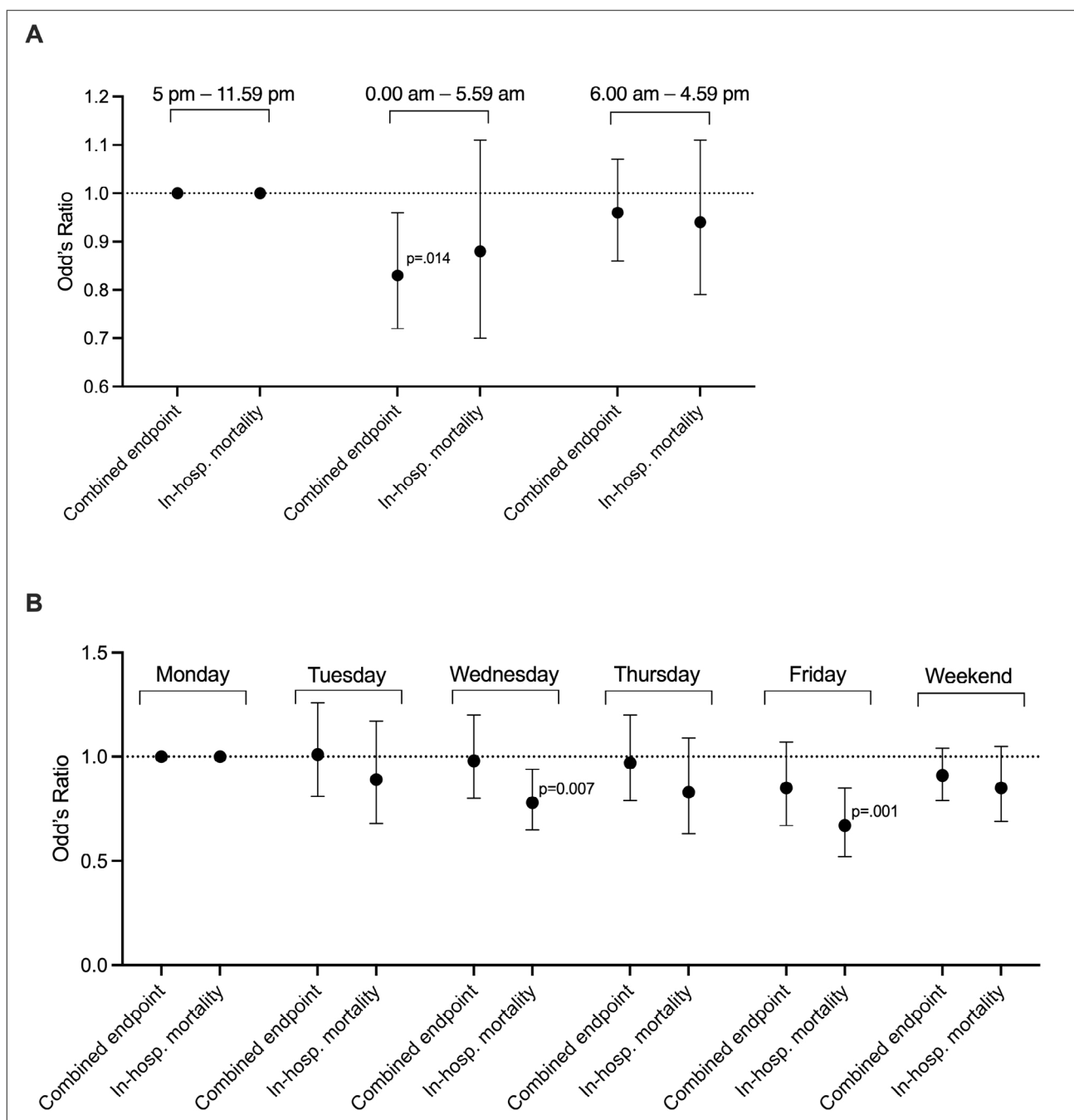


Figure 1. Odd's Ratio for combined endpoint and in-hospital mortality by weekday of the index surgery.

transplantation is highly centralized, performed exclusively in high-volume centers with continuous access to specialized surgical, anesthesiologic, interventional and intensive care expertise and is conducted irrespective of time of day or week.

There are several factors to be discussed in order to explain potential mechanisms for the absence of a timing effect in our data: First, transplantation surgery is

intrinsically organized as a 24/7 high-reliability specialty. Staffing models, pathways and perioperative workflows are explicitly designed to facilitate urgent, non-plannable procedures, even outside regular working hours. Second, transplantations, unlike elective oncologic or benign cases, are rarely postponed for organizational reasons, reducing selection bias related to case timing. Third, multidisciplinary decision-making, standard operating

procedures and experienced staff may mitigate risks associated with fatigue, handovers or reduced ancillary staffing.

In contrast to timing, patient-related factors had implications for adverse outcomes. Frailty, comorbidity burden, advanced age and acute liver failure and the indication for transplantation showed higher numbers of in-hospital mortality and morbidity. These findings reinforce the concept that outcomes after liver transplantation are mainly driven by recipient factors rather than organizational factors such as surgery timing. Transplant patients for acute liver failure showed the highest risk for worse outcomes which underscores the need for continued efforts to optimize perioperative management of this subgroup.

Strengths and limitations

The major strength of this study lies in its nationwide, population-based conduct, which encompasses all liver transplantations performed in Germany over more than a decade. Since the complete DRG billing data was used, selection bias related to center participation is eliminated. This also allows for robust estimates of real-world outcomes. Moreover, the incorporation of comorbidity measures as well as the use of mixed-effects modeling, strengthens the validity of the depicted results.

Nonetheless, several limitations must be considered. The current analysis is at risk of residual confounding. On the one hand, the use of administrative data precludes access to more granular clinical variables such as MELD score, donor characteristics, cold ischemia time or graft quality. More so, no pairing was possible between data of donors and recipients. On the other hand, all outcomes were limited to the in-hospital period, no long-term graft or patient survival data could be assessed. Data quality is furthermore limited by possible underreporting of minor complications in the DRG data system since they are not billable. Also, clinical data on vascular or biliary complications are not available. One factor not reflected in the data is timing preference of the conducting surgeons. With the surge of pre-transplantation perfusion machines, timing of liver transplantation might shift more toward routine hours than is already the case to be compliant with physiological working hours.

Notably, all limitations mentioned would be expected to bias results toward detecting differences rather than diminishing substantial effects. The consistent absence of a timing effect across multiple endpoints therefore supports the robustness of the here stated conclusions.

Organizational and clinical implications

Within a clinical perspective, our research provides reassurance that liver transplantation can be safely performed at any time of day and on any given day of the week within the German healthcare system. Implications

for organ acceptance could be that concerns about weekend or nighttime surgery should not primarily influence allocation of scheduling practices. With regards to health policy, our data support the effectiveness of the current organizational structures in German transplant centers. Efforts to improve patient outcomes should focus less on working hours and more on patient selection, perioperative optimization of recipients and post-operative complication management.

CONCLUSIONS

In this nationwide cohort study, the timing of liver transplantation – by time of day or weekday – was not significantly associated with increased in-hospital mortality, failure to rescue or major postoperative morbidity. Relevant outcomes were primarily driven by patient-related risk factors rather than organizational timing. Our findings support the current practice of around-the-clock liver transplantation and underscore the resilience of specialized transplant services in Germany – in delivering high-quality transplant care independent of surgical timing.

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Conflict of interest statement

The authors declare no conflict of interest.

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Author contributions

MT, SS: conducted the analyses, wrote and reviewed the manuscript; DK, PD, EP: assisted in statistical analyses and reviewed the manuscript; PD, JD: reviewed the analyses and oversaw data aggregation in collaboration with the statistical office in Germany; AW, TB: were in charge of the project administration, reviewed the data analyses and the manuscript, and provided financial support; KU: was in charge of all steps of data acquisition, data analyses and interpretation, and writing and reviewing of the manuscript.

Ethical consideration

Our study adheres to the 2013 Helsinki Declaration. Multiple review boards on consensus guidelines have

determined that using anonymised data from claims or national statistics retrospectively does not constitute human subject research, as de-identified datasets were utilised. Based also on German legislation, no ethical approval was required for this large-scale, nationwide cohort analysis.

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APPENDIX

Supp. Table I. ICD and OPS codes for identification of procedures, additional therapies and comorbidities.

OPS Codes: main surgery
5-504
ICD Codes: main diagnosis
Alcohol-associated liver disease: K70 PSC: K83 PBC K74.3 Hepatocellular carcinoma: C22 Acute liver failure: K72.
ICD Diagnoses: side diagnoses and complication occurrence
Hepatic encephalopathy: K72 CHILD Stage: /4 Previous organ loss by surgery: Z90.3, Z90.4, Z90.5, Z90.6 Stoma by previous abdominal surgery: Z93.1, Z93.2, Z93.3, Z93.4, Z93.5, Z93.6 Status post organ transplant: Z94, Z94.4 Septic shock: R57.2 Pneumonia: J12-J18, U69 Adult ARDS: J80 PAE: I26 Portal vein thrombosis: I81 Mesenterial ischemia: K55 Myocardial infarction: I21, I22, I23 Stroke: I63 Chronic heart failure: I25, I11, I13, I13.2, I42, I42.6, I42.7, I42.9, I50 Arterial hypertension: I10, I11.9, I12.9, I13.9, I15 Chronic kidney disease: I12.9, I13.1, I13.2, N03, N04, N05, N07, N08, N11, N12, N14, N15, N16, N18, N19, Z99.2 Dialysis: Z99.2 COPD: J44.8, J44.9 Diabetes mellitus: E10, E11, E12, E13, E14 Obesity: E66 Kachexia: R64, R63.4, E43, E44 Therapeutic anticoagulation: I48, Z95.2, I26, I80 Pleural empyema: J86
OPS codes: complication occurrence
Colon resections: 5-455 (Partial resection of colon) Rectum resections: 5-485, 5-484 Enteric procedures: 5-454 Gastric procedures: 5-433, 5-434, 5-435, 5-436 Relaparotomy: 5-541.2, 5-541.3 ERC(P): 5-513 PTCD: 5-514.53, 5-514.g3, 5-514.m3, 5-514.n3, 5-514.h3 Angiography: 8-836 Blood transfusion (more than 6 erythrocyte concentrates): 8-800.c1-9, 8-800.ca-r Mechanical ventilation: 8-713, 8-714 Re-liver-transplantation: 5-504.3-5 ECMO: 8-852 CVVHD: 8-854.6, 8-854.7, 8-855.7, 8-855.8 CPR: 8-771 EC >10: 8-800.c2-8-800.cr TC >10: 8-800.6a-8-800.n9

EC: erythrocyte concentrate; TC: thrombocyte concentrate; ECMO: extracorporeal membrane oxygenation; CVVHD: continuous veno-venous hemodialysis; CPR: cardiopulmonary resuscitation. CVVHD was set to "none" in case of known dialysis before the transplantation.

Supp. Table II. Patient characteristics by main indication for transplantation.

	Overall	Alcohol-associated Liver disease	PSC or PBC	Hepatocellular carcinoma	Acute liver failure	Other
Total no. of patients n (%)	8,492	1,826 (21.5)	883 (10.4)	1,609 (18.9)	729 (8.6)	3,445 (40.6)
CHILD Score unknown n (%)	6,578 (77.5)	1,297 (71)	709 (80.3)	1,178 (73.2)	674 (92.5)	2,720 (79)
CHILD Score A n (%)	423 (5)	42 (2.3)	20-30	240 (14.9)	≤10	109 (3.2)
CHILD Score B n (%)	614 (7.2)	147 (8.1)	60-70	140 (8.7)	≤10	250 (7.3)
CHILD Score C n (%)	877 (10.3)	340 (18.6)	75 (8.5)	51 (3.2)	45 (6.2)	366 (10.6)
Coded hepatic encephalopathy any n (%)	1,621 (19.1)	447 (24.4)	78 (8.8)	66 (4.1)	408 (56.0)	622 (19.1)
Grade 1	435 (5.1)	115 (6.3)	24 (2.7)	23 (1.4)	92 (12.6)	181 (5.3)
Grade 2	522 (6.2)	141 (7.7)	30 (3.4)	20 (1.2)	124 (17)	207 (6)
Grade 3	478 (5.6)	138 (7.6)	15 (1.7)	17 (1.1)	137 (18.8)	171 (5)
Grade 4	186 (2.2)	53 (2.9)	9 (1)	6 (0.4)	55 (7.5)	63 (1.8)
Comorbidities n (%) Chronic heart failure	1,118 (13.2)	304 (16.6)	75 (8.5)	228 (14.2)	68 (9.3)	443 (12.9)
Arterial hypertension	3,057 (36)	671 (36.8)	222 (25.1)	789 (49)	213 (29.2)	1,162 (33.7)
Diabetes mellitus	2,559 (30.1)	618 (33.8)	154 (17.4)	708 (44)	137 (18.8)	942 (27.3)
Chronic obstructive pulmonary disease	241 (2.8)	82 (4.5)	8 (0.9)	63 (3.9)	10 (1.4)	78 (2.3)
Obesity	800 (9.4)	189 (10.4)	33 (3.7)	180 (11.2)	79 (10.8)	319 (9.3)
Therapeutic anticoagulation	1,277 (15)	332 (18.2)	73 (8.3)	205 (12.7)	133 (18.2)	534 (15.5)
Previous abdominal surgery	2,418 (28.5)	455 (24.9)	263 (29.8)	351 (21.8)	188 (25.8)	1,161 (33.7)
Kachexia/malnutrition	825 (9.7)	174 (9.5)	116 (13.1)	93 (5.8)	60 (8.2)	382 (11.1)
Chronic kidney disease	1,809 (21.3)	512 (28)	91 (10.3)	229 (14.2)	92 (12.6)	885 (25.7)
Pre-transplant dialysis	171 (2)	50 (2.7)	6 (0.7)	5 (0.3)	6 (0.8)	104 (3)

LD: liver disease; LF: liver failure. Values in parentheses are percentages of the total in the patient group unless otherwise indicated.

Supp. Table III. Frequencies by weekday of surgery and time of surgery by main indication for transplantation.

	Overall	Alcohol-associated Liver disease	PSC or PBC	Hepatocellular carcinoma	Acute liver failure	Other
Total no. of patients n (%)	8,492	1,826 (21.5)	883 (10.4)	1,609 (18.9)	729 (8.6)	3,445 (40.6)
Surgery by weekday: Monday n (%)	786 (9.3)	150 (8.2)	81 (9.2)	151 (9.4)	77 (10.6)	327 (9.5)
Tuesday	1,209 (14.2)	279 (15.3)	123 (13.9)	210 (13.1)	106 (14.5)	491 (14.3)
Wednesday	1,453 (17.1)	311 (17)	158 (17.9)	261 (16.2)	127 (17.4)	596 (17.3)
Thursday	1,396 (16.4)	305 (16.7)	146 (16.5)	282 (17.5)	115 (15.8)	548 (15.9)
Friday	1,313 (15.5)	280 (15.3)	135 (15.3)	264 (16.4)	106 (14.5)	528 (15.3)
Weekend	2,335 (27.5)	501 (27.4)	240 (27.2)	441 (27.4)	198 (27.2)	955 (27.7)
Time of surgery n (%) 0.00 am – 5.59 am	1,584 (18.7)	328 (18)	140 (15.9)	305 (19)	160 (22)	651 (18.9)
6.00 am – 4.59 pm	4,957 (58.4)	1,061 (58.1)	515 (58.3)	951 (59.1)	406 (55.7)	2,024 (58.8)
5 pm – 11.59 pm	1,951 (23)	437 (23.9)	228 (25.8)	353 (21.9)	163 (22.4)	770 (22.4)

LD: liver disease; LF: liver failure. Values in parentheses are percentages of the total in the patient group unless otherwise indicated.

Supp. Table IV. Combined endpoint by main indication for transplantation.

	Overall	Alcohol-associated Liver disease	PSC or PBC	Hepatocellular carcinoma	Acute liver failure	Other
Total no. of patients n (%)	8,492	1,826 (21.5)	883 (10.4)	1,609 (18.9)	729 (8.6)	3,445 (40.6)
Any complication occurrence n (%)	5,845 (68.8)	1,333 (73)	533 (60.4)	863 (53.6)	602 (82.6)	2,514 (73.0)
Failure to rescue n (%)	1,053	241 (18.1)	80 (15)	113 (13.1)	144 (23.9)	475 (18.9)
Overall occurrence of combined endpoint (LOS > 75th percentile age group and diagnosis group, Relaparotomy, Re-liver-transplantation, death) n (%)	3,215 (37.9)	721 (39.5)	301 (34.1)	433 (26.9)	375 (51.4)	1,385 (40.2)
In-hospital mortality	1,068 (12.6)	244 (13.4)	83 (9.4)	115 (7.2)	145 (19.9)	481 (14)
LOS > 75th percentile age group and diagnosis group	536 (6.3)	114 (6.2)	52 (5.9)	92 (5.7)	58 (8)	220 (6.4)
Relaparotomy	2,523 (29.7)	573 (31.4)	245 (27.8)	334 (20.8)	271 (37.2)	1,100 (31.9)
Re-Liver-transplantation	473 (5.6)	83 (4.6)	49 (5.6)	93 (5.8)	49 (6.7)	199 (5.8)

LD: liver disease; LF: liver failure. Values in parentheses are percentages of the total in the patient group unless otherwise indicated.

Supp. Table V. Complication occurrence in detail.

Number of patient records	8,492
Patient records with at least one complication	5,845 (68.8)
Surgical complications	
Portal vein thrombosis	923 (10.9)
Mesenterial ischemia	315 (3.7)
Relaparotomy	2,523 (29.7)
Pleural empyema	72 (0.9)
Re-liver-transplantation	473 (5.6)
Any gastric procedure	38 (0.5)
Any enteric procedure	164 (1.9)
Any colon procedure	167 (2)
Any rectal procedure	6 (0.1)
Splenectomy	126 (1.5)
Interventionally treated complications	
ERC(P)	1,358 (16)
PTCD	271 (3.2)
Angiography	623 (7.3)
Other complications	
Transfusion (> 10 EC)	4,050 (47.7)
Transfusion of TC (> 10 TC)	840 (9.9)
Pneumonia	1,799 (21.2)
PAE occurrence	143 (1.7)
ARDS	230 (2.7)
ECMO	137 (1.6)
Septic shock	704 (8.3)
CVVHD	2,776 (32.7)
CPR	441 (5.2)
Myocardial infarction	98 (1.2)
Stroke	93 (1.1)

EC: erythrocyte concentrate; TC: thrombocyte concentrate; ECMO: extracorporeal membrane oxygenation; CVVHD: continuous veno-venous hemodialysis; CPR: cardiopulmonary resuscitation; PTCD: percutaneous transhepatic cholangiodrainage; ERC(P): endoscopic retrograde cholangiography (/including pancreatigography).

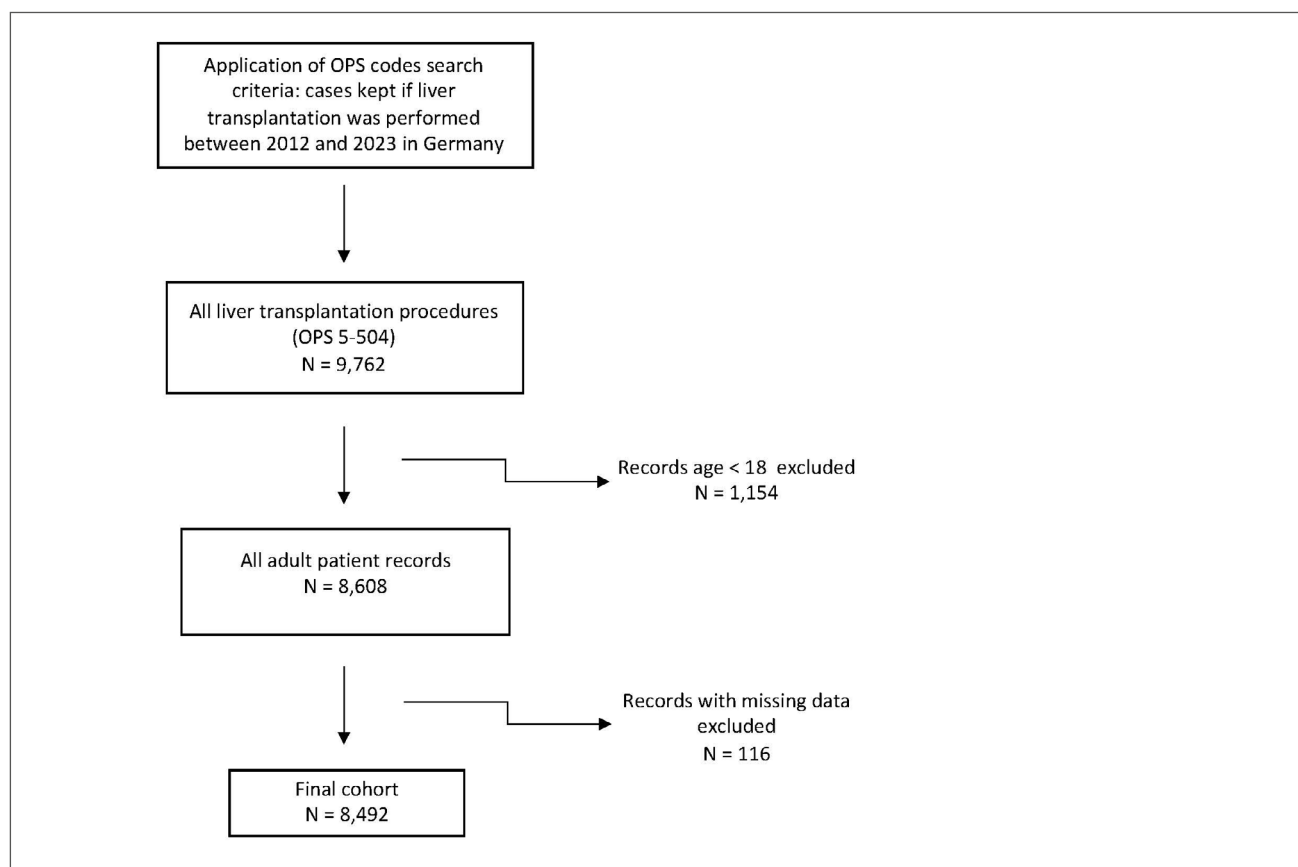
Supp. Table VI. Multivariable logistic regression model for combined endpoint occurrence.

	Multivariable logistic regression model for combined endpoint occurrence	
	Odd's Ratio [95% CI]	p value
Age (years)		
≤ 49	1	
50–59	0.79 [0.71-0.89]	< .001
≥ 60	0.77 [0.68-0.87]	< .001
Sex		
Female	1	
Male	0.98 [0.91-1.06]	.671
Charlson comorbidity index		
0	1	
1	1.43 [1.19-1.72]	< .001
2	1.52 [1.25-1.84]	< .001
3	2.19 [1.79-2.68]	< .001
Main diagnosis		
Acute liver failure	1	
Alcohol-associated liver disease	0.57 [0.47-0.70]	< .001
PSC or PBC	0.47 [0.38-0.58]	< .001
Hepatocellular carcinoma	0.35 [0.29-0.43]	< .001
Other	0.59 [0.49-0.70]	< .001
Time of surgery		
5 pm – 11.59 pm	1	
0.00 am – 5.59 am	0.83 [0.72-0.96]	.014
6.00 am – 4.59 pm	0.96 [0.86-1.07]	.435
Index surgery performance		
Monday	1	
Tuesday	1.01 [0.81-1.26]	.950
Wednesday	0.98 [0.80-1.20]	.844
Thursday	0.97 [0.79-1.20]	.783
Friday	0.85 [0.67-1.07]	.164
Weekend	0.91 [0.79-1.04]	.163

Supp. Table VII. Multivariable logistic regression model for in-hospital mortality.

	Multivariable logistic regression model for in-hospital mortality	
	Odd's Ratio [95% CI]	p value
Age (years)		
≤ 49	1	
50-59	1.20 [1.06-1.36]	.005
≥ 60	1.42 [1.20-1.69]	< .001
Sex		
Female	1	
Male	0.89 [0.78-1.01]	.069
Charlson comorbidity index		
0	1	
1	1.36 [0.91-2.03]	.135
2	1.35 [0.93-1.98]	.116
3	2.10 [1.41-3.15]	< .001
Main diagnosis		
Acute liver failure	1	
Alcohol-associated liver disease	0.51 [0.36-0.74]	< .001
PSC or PBC	0.43 [0.28-0.65]	< .001
Hepatocellular carcinoma	0.26 [0.18-0.39]	< .001
Other	0.58 [0.40-0.83]	.003
Time of surgery		
5 pm – 11.59 pm	1	
0.00 am – 5.59 am	0.88 [0.70-1.11]	.279
6.00 am – 4.59 pm	0.94 [0.79-1.11]	.451
Index surgery performance		
Monday	1	
Tuesday	0.89 [0.68-1.17]	.400
Wednesday	0.78 [0.65-0.94]	.007
Thursday	0.83 [0.63-1.09]	.177
Friday	0.67 [0.52-0.85]	.001
Weekend	0.85 [0.69-1.05]	.124

CI: confidence interval.



Supp. Figure 1. Flowchart of patient record identification.