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ORIGINAL ARTICLE

Initiating a paediatric living donor liver transplant program in a resource-challenged environment: outcomes and lessons learned

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Abstract

Purpose Paediatric liver transplantation (PLT) is a life-saving yet complex procedure requiring coordinated multidisciplinary expertise. This study aimed to evaluate anaesthetic and surgical factors influencing outcomes in paediatric living donor liver transplantation at a newly established centre in Malaysia.

Methods We conducted a retrospective cohort study of 21 paediatric patients who underwent living donor liver transplantation between August 2019 and January 2024 at our centre. Perioperative variables including surgical duration, intraoperative blood loss, transfusion volume, and postoperative mechanical ventilation were analysed. Associations with three-year survival were assessed.

Results The median age of recipients was 33 months, with biliary atresia as the leading indication (66.7%). The median operative time was 10.9 h. Massive intraoperative bleeding occurred in 47.6% of patients, and 42.8% required massive transfusion. Median ventilator duration was 2 days, and the three-year survival rate was 70.6%. Intraoperative blood loss ($p = 0.03$) and prolonged ventilation ($p = 0.01$) were significantly associated with reduced survival. Higher PELD scores and operative duration > 600 minutes were also associated with prolonged ventilation and increased mortality.

Conclusions Massive blood loss, prolonged operative duration, and delayed extubation significantly affect outcomes in PLT. Strengthening perioperative haemodynamic and ventilation strategies is crucial to improve survival in resource-limited transplant settings.

Keywords Paediatric liver transplantation · Paediatric End-Stage Liver Disease (PELD) score · Intraoperative blood loss · Operative time · Mechanical ventilation · Survival rate

Introduction

Paediatric liver transplantation (PLT) is a life-saving procedure for children with end-stage liver disease (ESLD) [1], with biliary atresia remaining the most common indication globally [2]. Despite advancements in surgical techniques, organ procurement, and immunosuppression, PLT remains a complex and high-risk procedure requiring a multidisciplinary approach. Long-term graft survival and patient outcomes are influenced by a range of factors, including preoperative patient status, intraoperative management, and postoperative critical care strategies [3].

Liver transplantation was first introduced in Malaysia in 1993, with the initial procedure undertaken within the private healthcare sector [4]. In 2000, a national referral centre for liver disease programme was initiated at Hospital Selayang. However, it was discontinued in 2015 due to various challenges, including the low rate of deceased donor organ donation [4]. Between 1975 and 2011, there were only 345 deceased donors, and by 2022, the national donation rate remained critically low at 0.7 per million population [5]. This scarcity is largely attributed to religious and

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cultural influences, particularly within the Muslim community, which significantly affect donor consent and acceptance [6].

In response to the critical shortage of transplantation services, the University of Malaya Medical Centre (UMMC) established itself in 2019 as a leading centre for living-related paediatric liver transplantation in Malaysia. The program in UMMC, developed in collaboration with Renji Hospital in Shanghai, China, aims to improve access to liver transplantation while enhancing perioperative management through international knowledge exchange and expertise-sharing. However, the rapid development of the program has been met with challenges, including the impact of the COVID-19 pandemic on onsite training resources from our collaboration with surgeons from Renji Hospital, necessitating adaptive strategies to maintain transplant success rates in our centre.

Optimising perioperative management is crucial for improving transplant outcomes in paediatric patients, as intraoperative factors such as blood loss, haemodynamic stability, ischaemic time, and transfusion practices have been shown to significantly impact survival rates [7]. Anaesthetic management in PLT is particularly demanding, requiring real-time coagulation monitoring, haemodynamic stabilization, and meticulous fluid and blood product administration to mitigate the risks associated with massive transfusion and prolonged ischaemia [8]. Similarly, surgical factors such as anhepatic phase duration, graft selection, and vascular anastomosis techniques influence both short- and long-term patient outcomes (EASL Clinical Practice Guidelines: Liver Transplantation [9]. Moreover, prolonged mechanical ventilation postoperatively has been associated with adverse outcomes, emphasising the need for perioperative optimisation [10].

This study aimed to evaluate the anaesthetic and surgical factors influencing outcomes in paediatric liver transplantation at the UMMC, a newly established centre for paediatric living-related liver transplantation in Malaysia. Specifically, the study investigated key intraoperative parameters, including surgical duration, intraoperative blood loss, transfusion requirements, and haemodynamic variations. Additionally, postoperative outcomes such as ventilator dependency, paediatric intensive care unit (PICU) length of stay (LOS), and three-year survival rates were analysed to identify perioperative predictors of morbidity and mortality.

Materials and methods

Study design and setting

This retrospective cohort study was conducted at the University of Malaya Medical Centre (UMMC), a quaternary referral hospital in Malaysia, specializing in paediatric liver transplantation. Ethical approval was obtained from the Medical Research Ethics Committee of University of Malaya Medical Centre (Ethics approval number: 20161122-4622). The study adhered to the STROBE guidelines for observational studies [11].

Patient population

Paediatric patients who underwent living-donor liver transplantation (LDLT) between August 2019 and January 2024 were included. Inclusion criteria were: (1) age < 18 years at transplantation, (2) availability of complete perioperative records, and (3) documented follow-up of at least three years. Exclusion criteria included multi-organ transplants and re-transplantation cases.

Intraoperative management

During the study period, 21 paediatric patients underwent liver transplantation under general anaesthesia. Standard induction agents were administered, including fentanyl (2 mcg/kg), propofol (4 mg/kg), and atracurium (0.5 mg/kg). Anaesthesia was maintained with sevoflurane in an air-oxygen mixture, while remifentanil was infused continuously for analgesia, and atracurium was used as a muscle relaxant.

Comprehensive intraoperative monitoring was conducted for all patients, including capnography, central venous pressure monitoring, invasive arterial blood pressure measurement, central core temperature monitoring, and urinary catheterisation. Active warming strategies were implemented using air-warming blankets, with the operating theatre maintained at a controlled temperature of 22 °C. To facilitate haemodynamic monitoring and rapid resuscitation if required, a central venous catheter was inserted, along with a radial arterial catheter. Peripheral intravenous access was secured in the upper limbs due to the necessity for inferior vena cava clamping.

Baseline laboratory investigations, including arterial blood gases, serum glucose, sodium, potassium, and ionized calcium levels, were performed at the time of vascular access placement. Intraoperative arterial blood gas monitoring was conducted at regular intervals. Rotational thromboelastometry (ROTEM) was introduced to guide intraoperative blood product administration, while a cell salvage system was employed to mitigate the impact of massive haemorrhage.

All patients received prophylactic intravenous antibiotics, which included ampicillin, ceftriaxone, metronidazole, or meropenem, depending on their individual culture and antimicrobial resistance profiles. Haemodynamic stability was maintained with vasoactive agents such as norepinephrine and vasopressin, as clinically indicated. Immunosuppressive

therapy, comprising intravenous basiliximab, was administered immediately prior to graft reperfusion in all our paediatric liver transplant recipients, except for the first patient, in whom high-dose steroids were used instead. Tranexamic acid was not routinely administered due to concerns regarding its potential association with arterial and venous thrombosis; its use was considered on a case-by-case basis following multidisciplinary team discussion. Patients who received fresh frozen plasma (FFP) and autologous blood salvaged via cell saver were supplemented with intravenous calcium chloride to maintain normocalcaemia.

Surgical approach

Of the 21 LDLTs done, there was only one right donor lobe; the others were all left lateral liver lobes. Vascular control was done using vascular clamps to the inferior vena cava and slings to the hepatic veins after careful dissection. All anastomoses for the hepatic and portal veins were done in a continuous manner, end-to-side to the inferior vena cava. Redo anastomosis was required for two patients after Doppler revealed poor flows. Portal vein anastomosis was done end-to-end, with two cases requiring redo anastomosis due to poor intraoperative Doppler flow. Common hepatic artery anastomosis was done end-to-end, with two patients requiring interpositional grafts (one using the recipient's inferior epigastric artery and the other using the recipient's great saphenous vein). All vascular anastomoses were checked with intraoperative and postoperative Doppler flows.

At the conclusion of the procedure, all patients were transferred to the paediatric intensive care unit (PICU) for postoperative monitoring and continued management.

Postoperative management

Postoperative immunosuppressive therapy primarily consisted of tacrolimus, with basiliximab introduced as part of combination therapy. Routine postoperative monitoring included daily blood tests and Doppler ultrasound assessments of the transplanted liver during the first postoperative week, followed by biweekly evaluations thereafter. Anticoagulation therapy with either unfractionated heparin or low-molecular-weight heparin (LMWH) was routinely administered once contraindications were excluded. Aspirin was initiated upon the resumption of a regular diet in patients with a low bleeding risk, defined as a platelet count > 50,000/mm^3 and a prothrombin time-international normalized ratio (PT-INR) < 2.

Data collection and variables

Demographic, clinical, intraoperative, and postoperative data were retrieved from electronic medical records and anaesthesia logs. Data were categorised as follows:

- **Preoperative parameters:** Age, gender, weight, Paediatric End-Stage Liver Disease (PELD) score, primary diagnosis, and history of previous abdominal surgeries.
- **Intraoperative parameters:** Total surgical duration, anhepatic time, estimated blood loss (EBL), intraoperative transfusion of packed red blood cells (pRBCs), fresh frozen plasma (FFP), platelets, and cryoprecipitate. Haemodynamic parameters, including vasopressor requirement and metabolic variables (lactate, bicarbonate, sodium, and glucose) before and after reperfusion, were documented.
- **Postoperative outcomes:** Duration of mechanical ventilation, length of stay (LOS) in the paediatric intensive care unit (PICU), early postoperative complications, and three-year survival rate.

Definitions and standardization

- **Massive blood loss:** Defined as the loss of one circulating blood volume in 24 h or 50% of the blood volume within 3 h [12].
- **Massive blood transfusion:** Defined as transfusion volume exceeding the patient's estimated blood volume during the intraoperative period [13].
- **One-year survival:** Defined as time from transplantation to last follow-up or death.

Statistical analysis

Continuous variables were reported as medians with interquartile ranges (IQRs), while categorical variables were expressed as absolute values and percentages. Normality was assessed using the Shapiro–Wilk test. Comparisons between groups were made using the Mann–Whitney U test for continuous variables and Pearson's Chi-square test for categorical variables. Kaplan–Meier survival analysis was used to estimate survival probabilities, and Cox proportional hazard models were applied to identify independent predictors of survival. A p-value < 0.05 was considered statistically significant. All analyses were conducted using SPSS v27 (IBM Corp., Armonk, NY, USA).

Results

The study included 21 paediatric liver transplant recipients. The demographic and clinical characteristics of the patients are described in Table 1. The median age of the recipients was 33.0 (IQR 13.0–73.5) months, with a median weight of 10.7 (IQR 8.4–17.8) kg. The majority (66.7%) had biliary atresia as the primary indication for transplantation, while a smaller proportion presented with acute liver failure (14.3%) and Alagille syndrome (4.8%). The median

Paediatric End-Stage Liver Disease (PELD) score was 19.6 (IQR 14.2–24.2), reflecting the severity of liver dysfunction in this cohort.

Intraoperative characteristics

The median operative duration was 10.9 (IQR 9.3–12.0) hours, with a median anhepatic phase of 60.0 (IQR 48.5–74.0) minutes. Massive intraoperative blood loss occurred in 47.6% of patients, with 42.8% requiring transfusion. Blood product administration included packed red blood cells (pRBCs), fresh frozen plasma (FFP), and cryoprecipitate. Detailed intraoperative characteristics are summarized in Table 2.

Table 1 Recipient demographics and their Donors' details ($n = 21$)

Category	Number (%) or Median (IQR) ($n = 21$)
Recipient demographics	
Male	12 (57%)
Female	9 (43%)
PELD score	19.6 (14.2–24.2)
Recipient age (month)	33.0 (13.0–73.5)
Recipient age > 1 year	12 (57.1%)
Recipient weight (kg)	10.7 (8.4–17.8)
Recipient diagnosis	
Biliary atresia	14 (66.7%)
Alagille syndrome	3 (14.3%)
Acute liver failure	3 (14.3%)
Autoimmune sclerosis cholangitis	1 (4.8%)
Donors' gender	
Males	6 (28.6%)
Females	15 (71.4%)
Donor to recipient relation	
First-degree relatives	18 (85.7%)
Second-degree relatives	3 (14.3%)

Postoperative outcomes

The median length of stay (LOS) in the PICU was 15.0 (IQR 9.0–28.5) days, with a median duration of mechanical ventilation of 2.0 (IQR 1.0–7.5) days. The overall three-year survival rate was 70.6%.

Risk factors associated with patients' survival outcomes

The factors associated with patient survival are summarized in Table 3. Among the intraoperative variables, significant predictors of survival included intraoperative estimated blood loss (EBL) (median: 852.5 ml [IQR 575.0–2625.0]; $p = 0.03$) and prolonged postoperative mechanical ventilation (median: 2.0 days [IQR 1.0–7.5]; $p = 0.01$).

The association between perioperative variables and the duration of mechanical ventilation in the paediatric liver transplant cohort is presented in Table 4. A significant correlation was identified between the preoperative Paediatric End-Stage Liver Disease (PELD) score and ventilator duration (median: 19.6 [IQR 14.2–24.2]; $p < 0.01$). Similarly, intraoperative blood loss was significantly associated with prolonged mechanical ventilation (median: 852.5 ml [IQR 575.0–2625.0]; $p = 0.05$). However, other factors, including operative duration, packed red blood cell transfusion, and intraoperative fluid administration, did not demonstrate significant correlations with ventilator duration.

The analysis of baseline and perioperative characteristics (Table 5) identified prolonged operative time (> 600 minutes) and massive intraoperative blood loss as factors reaching statistical significance ($p = 0.05$) in relation to mortality. Notably, no deaths were observed among recipients with

Table 2 Patients' intraoperative characteristics

Category	Number (%) or Median (IQR)
Recipient with massive bleeding	10 (47.6%)
Recipient required massive blood transfusion	9 (42.8%)
Fluid and blood products transfused	
Crystalloid (ml)	650 (414–1015)
Colloid (ml)	1200.0 (287.5–1620.0)
Packed red blood cells (pRBCs) and cell saver (ml)	743 (427–2266)
Fresh frozen plasma (ml)	303.0 (0–710.5)
Platelet (ml)	0 (0–202.5)
Cryoprecipitate (ml)	194.0 (0–486.5)
Operative time (hour)	10.9 (9.3–12.0)
Anhepatic phase (minute)	60.0 (48.5–74.0)
Intraoperative blood loss (ml)	852.5 (575.0–2625.0)

Table 3 Factors that may contribute to survival outcome

Variable	Median (IQR)	Survival outcome (*p*-value)
PELD score	19.6 (14.2–24.2)	0.34
Operation duration (hour)	10.9 (9.3–12.0)	0.11
Intraoperative EBL (ml)	852.5 (575.0–2625.0)	**0.03***
Intraoperative fluid balance (ml)	1702.0 (768.0–2583.5)	0.52
pRBCs transfusion (ml)	743 (427–2266)	0.07
FFP transfusion (ml)	303.0 (0–710.5)	0.11
Crystalloid (ml)	650 (414–1015)	0.68
Colloid (ml)	1200.0 (287.5–1620.0)	0.06
Anhepatic duration (minute)	60.0 (48.5–74.0)	0.10
Mechanical ventilation duration (day)	2.0 (1.0–7.5)	**0.01***
PICU LOS (day)	15.0 (9.0–28.5)	0.24

Table 4 Variable association with the duration of mechanical ventilation days

Variable	Median (IQR)	Increased ventilator day (*p*-value)
PELD score	19.6 (14.2–24.2)	**< 0.01***
Operation duration (hour)	10.9 (9.3–12.0)	0.08
Intraoperative blood loss (ml)	852.5 (575.0–2625.0)	**0.05***
Packed cell transfusion during operation (ml)	743 (427–2266)	0.19
FFP transfusion during operation (ml)	303.0 (0–710.5)	0.16
Crystalloid usage during operation (ml)	650 (414–1015)	0.18
Colloid usage during operation (ml)	1200.0 (287.5–1620.0)	0.12
Anhepatic duration (minute)	60.0 (48.5–74.0)	0.51

operative times < 600 minutes, whereas mortality occurred in 6 patients (28.6%) with operative durations exceeding 600 min. Similarly, massive intraoperative blood loss was reported in 5 (23.8%) deceased patients and 5 (23.8%) survivors ($p = 0.05$). In contrast, no significant associations were observed between mortality and other factors, including age, gender, preoperative weight, aetiology of liver failure, history of prior abdominal surgery, or haemodynamic and metabolic parameters (all $p > 0.05$).

Among the six reported deaths (Table 6), two were attributed to severe sepsis (*E. coli* septicaemic shock and disseminated invasive candidiasis), two to graft failure, one to intracranial haemorrhage, and one to disseminated intravascular coagulation (DIC). One patient underwent relaparotomy for a perforated transverse colon, while another required craniotomy for clot evacuation due to a left middle cerebral artery infarct with haemorrhagic transformation.

BA: biliary atresia; COVID-19: coronavirus disease 2019; DIC: disseminated intravascular coagulation; E. coli: *Escherichia coli*; ICH: intracerebral haemorrhage; LDLT: living-donor liver transplantation; MIS-C: multisystem inflammatory syndrome in children; POD: postoperative day; TTP: thrombotic thrombocytopenic purpura.

Discussion

In this study, most paediatric liver transplant recipients at our centre had biliary atresia (66.7%), reflecting global trends where it remains the leading indication for transplantation [14, 15]. The median age at transplantation was 33 months, consistent with studies highlighting the benefits of early intervention for growth and neurodevelopment in children with biliary atresia and native liver disease [16]. The median PELD score of 19.6 (IQR 14.2–24.2; $p = 0.34$) was comparable to scores reported by other centres [17].

Our study identified key perioperative factors influencing morbidity and mortality in paediatric living-related liver transplantation in our centre. Among these, PELD score, intraoperative blood loss, and duration of operation were significantly associated with prolonged ICU stay and mechanical ventilation days, early graft dysfunction, and survival rates.

1. PELD score:

Table 5 Characteristics between survival and deceased liver transplant patients ($n = 21$)

Variable		Survived, Number (%)	Deceased, Number (%)	*p*-value
Age	< 1 years old	4 (19.0)	1 (4.8)	0.55
	> 1 years old	11 (52.4)	5 (23.8)	
Gender	Male	8 (38.1)	4 (19.0)	0.48
	Female	7 (33.3)	2 (9.5)	
Weight	< 10 kg	7 (33.3)	3 (14.3)	0.63
	> 10 kg	8 (38.1)	3 (14.3)	
Liver failure	Acute	2 (9.5)	1 (4.8)	0.66
	Chronic	13 (61.9)	5 (23.8)	
History of previous abdominal surgery	Yes	11 (52.4)	5 (23.8)	0.55
	No	4 (19.0)	1 (4.8)	
Operation time	< 600 minutes	8 (38.1)	0 (0)	**0.05***
	> 600 minutes	7 (33.3)	6 (28.6)	
Blood loss	Massive	5 (23.8)	5 (23.8)	**0.05***
	Non-massive	10 (47.6)	1 (4.8)	
Blood transfusion	Massive	5 (23.8)	4 (19.0)	0.33
	Non massive	10 (7.6)	2 (9.5)	
Metabolic acidosis	Pre-perfusion	7 (33.3)	5 (23.8)	0.18
	Post-perfusion	9 (42.9)	4 (19.0)	1.00
Hyperlactataemia	Pre-perfusion	11 (52.4)	6 (28.6)	0.28
	Post-perfusion	14 (66.7)	6 (28.6)	1.00
Hyperglycaemia	Pre-perfusion	1 (4.8)	1 (4.8)	0.50
	Post-perfusion	2 (9.5)	2 (9.5)	0.54

In our study, higher recipient PELD scores were associated with prolonged mechanical ventilation, often reflecting perioperative instability, respiratory compromise, or post-transplant complications such as graft dysfunction, sepsis, or ventilator-associated pneumonia. This supports existing literature linking prolonged ventilation to increased mortality and extended ICU stays in paediatric liver transplant recipients [18]. However, as PELD scores are primarily designed to prioritise sicker children on the waitlist, their correlation with postoperative outcomes such as ventilation duration and graft survival is complex. A large single-centre study found PELD to be a poor predictor of post-transplant outcomes, suggesting that factors such as blood loss, ischaemic time, and ventilator dependence may have a more direct influence [19].

2. Massive intraoperative blood loss:

Massive intraoperative blood loss occurred in 47.6% of recipients, with 42.8% requiring massive transfusions, emphasizing the high perioperative risk of haemorrhage in paediatric liver transplantation. This is influenced by pre-operative hepatic dysfunction, coagulopathy, and surgical complexity [8]. Massive transfusion is often a surrogate marker for disease severity and is associated with poorer long-term patient survival [13]. Intraoperative bleeding and transfusion needs remain key challenges due to pre-existing coagulopathy, the complexity of surgery, and dynamic coagulation changes during transplantation [20]. Additional intraoperative factors such as hypothermia, citrate toxicity, and hypocalcaemia also contribute to blood loss [21]. Compared to other Asian centres, our rate of massive transfusion is lower than that reported by Jin et al. but higher than that by Huang et al [22, 23].

In our initial cases, significant intraoperative bleeding necessitated massive transfusions. To improve blood management, we adopted advanced conservation strategies aligned with the three pillars of patient blood management, including intraoperative cell salvage and ROTEM-guided transfusion [24, 25]. Both approaches have been shown to reduce unnecessary transfusions and enhance postoperative outcomes.

Table 6 Early mortality following paediatric LDLT ($n = 6$)

Patient	Indication for LDLT	Death (POD)	First major complication (POD)	Principal complications	Key interventions
1	BA, post Kasai	46	6	Acute rejection; bowel perforation × 2; persistent intra-abdominal sepsis	High-dose steroids; two relaparotomies & washouts
2	BA, post Kasai	0 (3 hours)	0	DIC with massive bleeding & haemodynamic collapse	Massive transfusion protocol
3	BA, post Kasai	11	5	Acute rejection; *E. coli* intra-abdominal sepsis	High-dose steroids; relaparotomy & washout; targeted antibiotics
4	BA, post Kasai	63	45	Disseminated *Candida* infection (lung, urine, peritoneum, blood)	Multiple systemic antifungals
5	Alagille syndrome	21	10	Cerebral infarction ± ICH; MIS-C (COVID-19)	Craniotomy & partial lobectomy; critical care for MIS-C
6	Acute liver failure (indeterminate)	50	12	Primary graft failure; TTP; fungaemia	High-dose steroids; plasma exchange; antifungals

3. Prolonged operative duration:

Prolonged operative time is a common challenge in paediatric liver transplantation, reflecting its complexity, including meticulous vascular anastomoses and extensive haemostatic management [26–28]. Our median operative time of 10.9 hours (IQR 9.3–12.0) aligns with other centres, while the median anhepatic phase of 60 minutes (IQR 48.7–74.5) falls within expected ranges. Extended anhepatic time is linked to greater metabolic instability, coagulopathy, and post-reperfusion haemodynamic changes [29].

4. Postoperative mechanical ventilation:

In our cohort, higher PELD scores ($p < 0.01$) and greater intraoperative blood loss ($p = 0.05$) were linked to prolonged postoperative ventilation, consistent with previous studies [30]. Operative and anhepatic times showed no significant association.

Prolonged ventilation was also associated with reduced survival ($p = 0.01$), infection risk, and extended PICU stays. Our median ventilator duration was two days, aligning with benchmarks. Early extubation reduces ventilator-related complications and improves survival [31, 32]. Lung-protective ventilation, including low tidal volumes and PEEP optimisation, may lower pulmonary complications and support graft function [33]. Standardised protocols remain essential for better outcomes.

5. Other perioperative variables:

Patient age, gender, weight, aetiology of liver failure, and prior abdominal surgery were not significantly associated with survival ($p > 0.05$), unlike other studies linking younger age and lower weight to poorer outcomes [34]. Metabolic and biochemical markers, including acidosis, hyperlactataemia, and hyperglycaemia, also showed no significant differences between survivors and non-survivors.

6. Survival rate & cause of mortality.

In our cohort, biliary atresia was the leading indication (66.7%), with survival outcomes consistent with previous reports showing favourable results in this group [33]. Our centre's three-year survival rate of 70.6% is slightly lower than the international benchmarks, reflecting our limited experience in paediatric liver transplant surgery [10].

In our cohort, 5 out of 6 patients (83%) died within 90 days postoperative, underscoring that the early post-transplant period is the highest-risk window. This critical phase corresponds with immediate graft function and reperfusion, induction of immunosuppression, heightened risk of nosocomial and opportunistic infections, and potential surgical complications such as bleeding or anastomotic leaks. Early mortality rates after paediatric liver transplantation have similarly been reported to be highest within the first 3 months, consistent with literature emphasizing this vulnerable period [35].

Sepsis was the leading cause of mortality in our cohort, consistent with previous findings highlighting severe sepsis as a major contributor to post-transplant deaths [36]. Prolonged PICU stays increase the risk of poor outcomes, largely due to immune dysregulation during critical illness, which heightens susceptibility to infections. Systemic fungal infections, in particular, have been associated with poor outcomes [37]. Risk factors include immunosuppression, repeated abdominal surgeries, and extended ICU stays, emphasizing the need for early detection, prompt antifungal therapy, and close monitoring.

Massive intraoperative bleeding and transfusion also contributed to adverse outcomes by altering the inflammatory cascade [38]. Transfusions may suppress immunity, increase infection risk, and complicate recovery. In the early post-transplant period, severe sepsis can lead to DIC and intracranial haemorrhage, driven by clotting activation and endothelial injury. Managing this dual risk of thrombosis and bleeding remains a critical challenge.

Graft failure is another major cause of mortality. As reported by Eckhoff et al., patients with graft failure may require retransplantation or risk death, with mortality rates of 17–30% [39]. Among our patients, 2 experienced primary graft dysfunction or acute rejection. Despite early surgical interventions including relaparotomy and bowel repair, persistent infection complicated graft recovery. Inadequate or delayed control of rejection likely contributed to progressive graft failure and systemic deterioration. This highlights the importance of timely, biopsy-confirmed diagnosis and aggressive escalation of immunosuppressive therapy in managing rejection, which aligns with current best practices [40].

Limitations and future directions

While this study offers insights into perioperative factors affecting paediatric LT outcomes, its retrospective design and small sample size limit causal inference and generalisability. Long-term graft function and quality of life were not assessed, highlighting the need for prospective studies.

Future research should focus on optimising intraoperative strategies to minimise blood loss and reduce operative time. Studies should also explore the impact of advanced coagulation monitoring, blood conservation techniques, and early extubation on improving survival in this high-risk group.

Conclusion

This study identified several factors, namely, PELD scores, prolonged operative time, and massive intraoperative blood loss, that have a significant influence on the outcomes of survival and prolonged ventilation in paediatric LT patients of UMMC. Therefore, our findings emphasize the critical role of intraoperative bleeding management, improving surgical operating time, postoperative ventilatory strategies, and haemodynamic stabilisation to obtain better outcomes. Future studies should continue to explore novel perioperative interventions to enhance survival rates and reduce morbidity in paediatric LT recipients.

Author contributions All authors contributed to the study conception and design. Data collection and analysis were performed by L.L.O., I.I.S., J.A.W.O., K.W.S.N., C.S.M. and N.I.A.R. The project was supervised by I.I.S. The original draft of the manuscript was written by L.L.O., J.A.W.O., K.W.S.N. and I.I.S. The manuscript was reviewed and edited by C.S.M., N.I.A.R., S.A.N. and P.S.L. All authors read and approved the final manuscript.

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Data availability The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest S.A.N. is an editorial board member of Pediatric Surgery International. The other authors declare that they have no competing interest.

Ethical approval This study was approved by the Medical Research Ethics Committee of the University of Malaya Medical Centre (Ethics approval number: 20161122-4622). The research was conducted in accordance with the Declaration of Helsinki.

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