INTRODUCTION

Living donor liver transplantation (LDLT) has become an established treatment option for patients with end-stage liver disease and hepatocellular carcinoma due to the shortage of deceased donor organs. The cornerstone of LDLT is donor safety. Living donors are the best candidates potentially to benefit from the advantages of laparoscopy by minimising wound injury,
donor morbidity, blood loss, transfusion rate and length of hospital stay.\[9\]

In 2002, Cherqui et al. performed the first laparoscopic donor left lateral sectionectomy (LLS) for paediatric LDLT.\[4\] Subsequently, several studies have shown the safety, feasibility and reproducibility of the technique that is now considered the standard of care by many centers.\[5,6\] Four years later in 2006, laparoscopy-assisted right lobe donor hepatectomy was reported.\[7\] Although in the world of minimal access surgery Ho-Seong Han is widely credited to have performed the first pure laparoscopic right donor hepatectomy (PLDH) as an alternative to the conventional open donor hepatectomy (ODH), it was Soubrane et al. who first described the procedure.\[8\] The expert consensus meeting on living donor hepatectomy held in Seoul, Korea in 2016 concluded that minimally-invasive donor hepatectomy (MIDH) is increasing its role in both paediatric and adult LDLT and during the meeting in 2019, guidelines were laid for safe implementation and development of MIDH in LDLT centres with the goal of optimising donor safety, donor care and recipient outcomes.\[2,8\] In the latter meeting, 44 recommendations were made on 18 clinical questions relating to MIDH and there was 90% consensus among experts favouring MIDH. The consensus was that PLDH is applicable to LLS and should be considered standard practice once the team has fulfilled the adequate training (2++ level of evidence, strong recommendation), whereas for selected right liver grafts and left liver grafts including middle hepatic vein (MHV), the level of evidence and recommendation was 2++ (strong) and 2-(conditional) respectively. However, it is very obvious that for major donor hepatectomy, there is a need for more evidence.\[10\] Laparoscopic donor major hepatectomy remains an extremely complex evolving technique with a steep learning curve.

In this review and meta-analysis, the current status of PLDH for adult LDLT is evaluated and the outcomes of PLDH assessed and compared to the standard open approach and provide insights on patient selection and technical issues that allow for safe implementation of this technique. Recipient outcomes following PLDH in terms of morbidity and mortality were also analysed.

MATERIALS AND METHODS

Search strategy
A search strategy in line with the meta-analysis of observational studies in epidemiology guidelines and previous recommendations for the conduction of systematic reviews of prognostic variables was developed.\[11\] An electronic search of Medline (1946-present), EMBASE (1974-), PubMed, Cochrane Library (1995-) and CINAHIL (1937-) and Google scholar was conducted independently by authors MP and ARH. All databases search was performed to identify studies evaluating peri-operative results of PLDH in adult LDLT. The search strategy was based on the following combination of terms: (laparoscopy × OR minimally invasive) AND (living OR live OR donor) AND (hepatectomy OR lobectomy). Thesaurus terms were further explored to identify additional studies. Only human studies were considered for inclusion. No restrictions were set for language or date. Bibliographies of relevant studies and the ‘related articles’ link in PubMed were used to identify additional studies. References of retrieved articles were also examined manually for further studies. Studies published only in abstract format or unpublished reports were excluded from the analysis. The last date for this search was 26 November, 2020. The Preferred Reporting Items for Systematic Reviews and Meta-analyses guidance was utilised\[12\] [Figure 1].

Inclusion criteria
Included studies analysed the outcome of PLDH for adult LDLT. Observational and comparative studies including more than 3 patients were considered for inclusion. The studies were carefully evaluated for duplication or overlapping of data. If an institution reported two studies, we included either the one of better quality (primary outcomes studied) or the most recent publication. In studies that included both laparoscopic-assisted and pure laparoscopic donor hepatectomies, the study was included if the data were available for pure laparoscopic patients with a sufficient subgroup analysis of this group of patients.

Exclusion criteria
Studies were excluded if they reported data from case reports (n < 4), there was overlap with institutions or patient cohorts already published in better quality studies. Studies involving laparoscopic-assisted, hand-assisted or hybrid techniques and robotic for donor hepatectomy were also excluded. Laparoscopic donor hepatectomies for paediatric LDLT were not included in our study.

Study selection
Two authors (MP and ARH) independently performed the search strategy. Both the authors reviewed the abstracts identified by the search to exclude those that did not meet our inclusion criteria. When no abstract was available or the abstract details were inadequate, the full article was reviewed. Differences between the two authors (MP and ARH) in selection of the studies were resolved by consensus with the third (NH) and fourth author (KVM), who independently
reviewed all retrieved papers to make the selection of studies robust.

Quality assessment
The Newcastle-Ottawa scale was used to assess the quality of included studies.[13] The level of evidence was independently determined by two authors (MP and ARH), identifying three main factors, including ‘the selection of study groups, comparability of the group and ascertainment of exposure/outcome’, with a number of items ranging from one to four per domain for cohort studies reporting only PLDH outcomes or comparing PLDH with open donor hepatectomies (ODH) outcomes. Each item was given a maximum score of one or two and the total score determines the quality of each study as summarised in Table 1.

Statistical analysis
The pooled mean of included studies was calculated by the following formula: Pooled mean of included studies = (N1 × M1 + N2 × M2 + N3 × M3)/(N1 + N2 + N3) where M1, M2 and M3 were the means of individual studies and N1, N2 and N3 were the number of patients in each study. In studies where the mean and variance were not provided, this was calculated using the median, range and sample size of the cohort, in accordance with the previously published studies.[22]

For categorical variables, the analysis was performed by calculating the odds ratio (OR). For continuous variable, the analysis was performed by calculating the standardised mean difference. The random effects, the DerSimonian-Laird method was used for the meta-analysis of outcomes.[23] Funnel plots were used to visually assess the publication bias of included studies. Heterogeneity between studies was assessed using the $I^2$ value to determine the degree of variation not attributable to chance alone. $I^2$ values were considered to represent low, moderate and high degrees of heterogeneity where values were <25%, 25%–75% and >75%, respectively. Funnel plot asymmetry was assessed using the Egger test.[24] Statistical significance was considered when $P < 0.05$. Statistical analysis was performed using the RevMan 5.4.1 software (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2020).

RESULTS
The search strategy identified a number of studies from the same centres with overlapping data, majority of them from Korean centres. The two centres with multiple overlapping publications were Seoul National University Hospital (SNUH)[25‑32] and Samsung Medical Centre (SMC).[33‑36] Two multicenter studies, one from the West[37] and one from the East[14] compiled data from multiple centres. Of this the Hong et al. included data from 5 Korean centres [SNUH, Seoul National University Bundang Hospital (SNUBH), SMC, Asan Medical Centre (AMC) and Kyungpook University Hospital (KNUH)] until June 2018 and was included.

Table 1: Study quality according to Newcastle-Ottawa Scale

| Study name          | Study year | Design                        | Number of PLDH | Selection | Comparability | Reliability | Total |
|---------------------|------------|-------------------------------|----------------|-----------|---------------|-------------|-------|
| Hong et al.[14]     | 2021       | Retrospective cohort study    | 506            | 3         | 2             | 3           | 8     |
| Hasegawa et al.[15] | 2019       | Retrospective cohort study    | 11             | 3         | 1             | 3           | 7     |
| Song et al.[16]     | 2018       | Retrospective cohort study    | 7              | 4         | 2             | 2           | 8     |
| Samstein et al.[17] | 2018       | Retrospective cohort study    | 20             | 4         | 3             | 2           | 9     |
| Takahara et al.[18] | 2017       | Retrospective cohort study    | 14             | 3         | 2             | 3           | 8     |
| Rotellar et al.[19] | 2017       | Retrospective cohort study    | 5              | 3         | 1             | 2           | 6     |
| Brustia et al.[20]  | 2015       | Retrospective cohort study    | 8              | 3         | 1             | 3           | 7     |
| Troisi et al.[21]   | 2013       | Retrospective cohort study    | 4              | 3         | 1             | 2           | 6     |

PLDH: Pure laparoscopic donor hepatectomy
due to the larger cohort size.\textsuperscript{[14]} The multicenter study by Soubrane \textit{et al.} included data from 2007 to 2017 from Belgium (1 centre), France (2 centres), Japan (3 centres), Spain (1 centre) and also data from 3 Korean centres (SNUH, SMC and AMC).\textsuperscript{[17]} Due to overlap of the Korean data in this study with the Hong \textit{et al.}, the multicentre study by Soubrane \textit{et al.} was excluded.

Eight studies were included for qualitative data synthesis on PLDH.\textsuperscript{[14–21]} For meta-analysis, only three of these eight studies compared data between PLDH and ODH\textsuperscript{[16,17,19]} and were from China, USA and Spain, respectively. However, majority of the published studies comparing PLDH and ODH are from the Korean centres, but the Hong \textit{et al.} Korean multicentre study included in the qualitative data synthesis did not compare PLDH and ODH.\textsuperscript{[14]} Hence, three studies published from Korean centres (SMC, SNUH and SNUBH) which reported on comparative data between PLDH and ODH\textsuperscript{[38–40]} were included in the meta-analysis. Hence, in total six studies were included in the meta-analysis.\textsuperscript{[16,17,19,38–40]}

### Donor and graft characteristics

In total, 575 PLDH donors were included in the systematic review\textsuperscript{[14–21]} [Table 2]. The mean donor age was 32.8 years, with the predominant male gender ($n = 303, 52.7\%$). The mean donor BMI was 23.4 kg/m$^2$. Procedures included right hepatectomy without MHV ($n = 504, 87.6\%$), right hepatectomy with MHV ($n = 16, 2.8\%$) and left hepatectomy ($n = 55, 9.6\%$). The mean graft weight was 675 g and the mean estimated remnant volume ranged from 38.2–68.6\%, the latter was only reported in three studies.\textsuperscript{[15,19,20]}

### Outcomes of donor hepatectomy

In total there were 16 open conversions (2.8\%) and one patient (0.2\%) was converted to hand-assisted procedure. The Pringle manoeuvre was sparingly used in the included studies ($n = 26, 4.5\%$), with a mean clamp time ranging from 17 to 51 min.\textsuperscript{[15,16,19,20]} The mean warm ischaemia time ranged from 5 to 9 min and mean operative time was 353 min. The estimated mean blood loss of 300 mL was reported in six studies ($n = 550$). Only four (0.7\%) of the 575 donors needed blood transfusion intraoperatively. The mean length of hospital stay was 9.2 days and was reported in seven studies ($n = 555$). The peak post-operative liver function tests were reported in three of the eight included studies and the mean serum bilirubin, mean AST and mean ALT were 4.1 mg/dL, 235 IU and 256 IU, respectively\textsuperscript{[49,14]} [Table 3].

In total, there were 19 bile leaks (3.3\%) of which one minor leak needing no intervention (Clavien-Dindo [CD] 1 or 2) and 18 required intervention (CD 3a or 3b). The overall morbidity in the included studies ranged from 0.0\% to 40.0\%. Eight (1.4\%) donors underwent re-laparotomy, of which three were for bleeding, two for bile leak and three for biliary stricture. There were no donor deaths in the included studies [Table 4].

### Recipient characteristics

The mean recipient age was 53.2 years, with a mean MELD of 14.2. The mean graft to recipient weight ratio was

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**Table 2: Baseline characteristics of pure laparoscopic donor hepatectomy donors of included studies**

| Author (reference) | Year | Country | Study period | Study design | Number of PLDH | Age, mean (years) | Male, n (%) | BMI, mean (kg/m$^2$) | Graft type (n) | Graft weight, mean (g) | Estimated remnant volume, mean (%) |
|--------------------|------|---------|--------------|--------------|----------------|------------------|------------|----------------------|-------------|------------------------|-------------------------------|
| Hong \textit{et al.}\textsuperscript{[14]} | 2021 | Korea   | 2010–2018 | Retrospective multicenter study | 506 | 31.9 | 275 (54.3) | 23.4 | RL without MHV (466) RL with MHV (15) LL with MHV (20) LL without MHV (5) | 686 | NR |
| Hasegawa \textit{et al.}\textsuperscript{[15]} | 2019 | Japan   | 2017–2019 | Retrospective cohort study | 11 | 37.7 | 5 (45.4) | NR | RL without MHV (8) LL with MHV (3) | 709 | 45.9 |
| Song \textit{et al.}\textsuperscript{[16]} | 2018 | China   | 2001–2017 | Retrospective cohort study | 7 | 42.7 | 3 (42.9) | 23.5 | RL without MHV (7) | 574 | NR |
| Samstein \textit{et al.}\textsuperscript{[17]} | 2018 | USA     | 2012–2017 | Retrospective cohort study | 20 | 39.8 | 3 (15.0) | 24.3 | RL without MHV (11) RL with MHV (1) LL with MHV (8) | 601 | NR |
| Takahara \textit{et al.}\textsuperscript{[18]} | 2017 | Japan   | 2012–2014 | Retrospective cohort study | 14 | 36.6 | 8 (57.1) | 21.4 | RL without MHV (5) LL without caudate (8) LL with caudate (1) RL without MHV (5) | 513 | NR |
| Rotellar \textit{et al.}\textsuperscript{[19]} | 2017 | Spain   | 2013–2015 | Retrospective cohort study | 5 | 38.0 | 4 (80.0) | 25.5 | RL without MHV (2) LL with or without MHV (6) LL with MHV (4) | 973 | 38.2 |
| Brustia \textit{et al.}\textsuperscript{[20]} | 2015 | France  | 2008–2014 | Retrospective cohort study | 8 | 44.5 | 3 (50.0) | 21.5 | RL without MHV (2) LL with or without MHV (6) LL with MHV (4) | 460 | NR |
| Troisi \textit{et al.}\textsuperscript{[21]} | 2013 | Belgium | NR         | Retrospective cohort study | 4 | 36.0 | 2 (50.0) | 23.7 | | 363 | 68.6 |

BMI: Body mass index, LL: Left lobe, MHV: Middle hepatic vein, NR: Not reported, RL: Right lobe, PLDH: Pure laparoscopic donor hepatectomy
Table 3: Perioperative pure laparoscopic donor hepatectomy donor characteristics and outcomes

| Author (reference) | Number of PLDH | Operative time, mean (min) | Presence of anatomical variations | Conversion (%) | Conversion causes | Pringle - Number of patients, mean (min) | WIT, mean (min) | Transfusion (%) | Estimated blood loss, mean (mL) | LoS, days | Readmission in 90 days (%) | Post-operative blood tests: Peak (mean) | TBIL mg/dL | AST/ALT (IU) |
|--------------------|----------------|---------------------------|----------------------------------|----------------|-----------------|------------------------------------------|----------------|----------------|-------------------------------|-----------|------------------------|----------------------------------------|-----------|-------------|
| Hong et al. [14]   | 506            | 341                       | Multiple bile ducts (105)        | 9 (1.8)        | Portal vein injury (3) Bleeding (2) | 11 (51)                  | 5.7            | 0              | 75*                          | 11*       | NR                     | NR                                           | 4.1       | 232/252     |
| Hasegawa et al. [15] | 11           | 410                       | NR                               | 1 (9.1)        | RHV bleeding due to stapler misfire (1) | 7 (41)                  | 6              | 0              | 378                          | 8.2       | 0                      | 2.9                                             | 490/487   |
| Song et al. [16]  | 7              | 509                       | Two separate PV branches (1) Two thick IHV (1) Two bile duct openings (1) | 0              | N/A              | 7 (41)                  | 6              | 0              | 378                          | 8.2       | 0                      | 2.9                                             | 490/487   |
| Samstein et al. [17] | 20           | 429                       | NR                               | 4 (20.0)       | Failure to progress (3) Slow transection/recipient need (1) | 0                       | NR             | 1 (5.0)        | NR                           | NR        | NR                     | NR                                           | NR        | NR          |
| Takahara et al. [18] | 14           | 454                       | Anomaly of biliary duct (1) Anomaly of hepatic artery (1) | 1 (assist)     | Hilar plate too thick to prepare the hepatic duct (1) | NR                     | 9              | 0              | 81                           | 8.4       | 3 (21.4)               | NR                                           | NR        | NR          |
| Rotellar et al. [19] | 5            | 476                       | Two separate bile ducts (2)      | 0              | N/A              | 5 (42.6)                  | N/A            | 0              | <100 ml in 4 cases, <200 ml in 1 case | 4.2       | 0                      | 2.0                                             | 242/329   |
| Brustia et al. [20] | 8             | 399                       | NR                               | 2              | Bile duct anatomy (1) Poor exposure (1) | 3 (17)                  | 7              | 0              | 86                           | 6.6       | NR                     | NR                                           | NR        | NR          |
| Troisi et al. [21] | 4             | 476                       | No                               | 0              | N/A              | 0                       | 5              | 0              | 57                           | 5.0*      | NR                     | NR                                           | NR        | NR          |

*Median. ALT: Alanine aminotransferase, AST: Aspartate aminotransferase, IHV: Inferior hepatic vein, LoS: Length of stay, N/A: Not applicable, NR: Not reported, PV: Portal vein, PVT: Portal vein thrombosis, TBIL: Total bilirubin, WIT: Warm ischaemia time, PLDH: Pure laparoscopic donor hepatectomy
only reported in four studies and the pooled mean was 1.09 (range: 0.65–1.14).\textsuperscript{[14,16,19,21]}

**Recipient outcomes**

There were 195 (34.4%) biliary complications in 567 recipients, the majority of which were from a single study (n = 186, 36.7% of the study population).\textsuperscript{[14]} There were 21 (3.7%) hepatic artery thrombosis/stenosis and 29 (5.1%) venous complications including portal vein thrombosis/stenosis and outflow obstruction. The re-operation rate was reported in only three studies, which was 5 out of 20 patients (25.0%).\textsuperscript{[16,18,21]} 90-day recipient mortality was reported in four studies\textsuperscript{[16,18,19,21]} and graft failure were only reported in three studies\textsuperscript{[16,18,21]} and pooled analysis was not possible due to very minimal dataset for these outcomes [Table 5].

**Meta-analysis**

Table 6 summarises the meta-analysis comparing PLDH with ODH.

Four studies\textsuperscript{[16,38–40]} reported on the estimated blood loss, which was less in the PLDH group (361 patients) when compared with the ODH group (626 patients) (weighted mean difference [WMD] −106.93; 95% confidence interval [CI] −215.64–1.78), but this did not reach statistical significance (P = 0.05) [Figure 2a]. The statistical heterogeneity of the studies was ‘substantial’ (I²: 89%). The funnel plot was symmetrical both according to visual and statistical testing (Egger test = 0.17), arguing against small-study effects of publication bias [Supplementary Figure 1a].

Five studies\textsuperscript{[16,19,38–40]} reported on the length of stay (LOS), which was less by a mean of nearly one day in the PLDH group (366 patients) when compared with the ODH group (636 patients) [WMD −0.73; 95% CI −1.34,‑0.12; P = 0.02] [Figure 2b]. The statistical heterogeneity of the studies was ‘substantial’ (I²: 74%). The funnel plot was symmetrical both according to visual and statistical testing (Egger test = 0.14), arguing against small-study effects of publication bias [Supplementary Figure 1b].

Five studies reported on overall morbidity and major complications, but this was no difference between the two groups\textsuperscript{[16,19,38–40]} [Figure 2c and d]. The statistical heterogeneity of the studies was ‘not important’ (I²: 0%) for both the comparisons [Supplementary Figure 1c and d].

Six studies reported on the mean operative time. The meta-analysis demonstrated that the operative time was significantly lower for the ODH group in comparison with the PLDH group [six studies; 386 PLDH
versus 656 ODH; WMD 29.15; 95% CI 8.53–49.77; \( P = 0.006 \) [Figure 2e]. The statistical heterogeneity of the studies was ‘substantial’ (I\(^2\): 60%). The funnel plot was symmetrical both according to visual and statistical testing (Egger test = 0.21), arguing against small-study effects of publication bias [Supplementary Figure 1e].

## DISCUSSION

Indications for laparoscopic liver surgery have expanded rapidly over the past decade.\(^{[41]}\) An increase in the cumulative experience of laparoscopic major hepatectomies within specialist centres has created a drive towards a minimally invasive approach in living donor hepatectomies. Since first reported in 2002,\(^{[4]}\) the role of laparoscopic donor hepatectomy in pediatric liver transplantation has been validated in numerous studies and is now considered ‘standard of care’ in many centres.\(^{[5,6]}\) However, pure laparoscopic donor hepatectomy (PLDH) for adult LDLT remains controversial.\(^{[2]}\) Published data of PLDH for adult LDLT are sporadic and come from a few high volume centres around the world (Korea, Japan, Europe, USA and China), reflecting the challenges of this technique.\(^{[3,14,37]}\)

### Table 5: Clinical characteristics and post-operative outcomes of pure laparoscopic donor hepatectomy recipients

| Author (reference) | Number of PLDH patients | Age, mean (years) | Aetiology (%) | MELD | GRWR | Biliary complications (%) | Vascular complications (%) | Reoperation 90 days mortality (%) | 90 days graft failure (%) |
|--------------------|-------------------------|-------------------|---------------|------|------|--------------------------|---------------------------|-----------------------------|--------------------------|
| Hong et al.\(^{[14]}\) | 506 | 53.4 | HBV (60.7) HCV (5.1) Alcohol (18.2) Others (16.2) | 14.3 | 1.1 | 186 (36.7) | 17 (3.3) | 26 (5.1)* | NR | NR | NR |
| Hasegawa et al.\(^{[15]}\) | 11 | NR | NR | | NR | NR | 3 (27.3) | 0 | 0 | NR | NR | NR |
| Song et al.\(^{[16]}\) | 7 | 40.6 | HBV (57.1) Malignancy (57.1) | 10 | 0.88 | 1 (14.3) | 0 | 0 | 1 (14.3) | 1 (14.3) | 1 (14.3) |
| Samstein et al.\(^{[17]}\) | 20 | NR | NR | | NR | NR | 0 | 1 (5.0) | 2 (10) | 0 | NR | NR | NR |
| Takahara et al.\(^{[18]}\) | 14 | 52.4 | Cholestatic disease (14.3) HCC (71.4) Malignancy (7.1) Others (7.1) | 14.8 | NR | 2 (14.3) | 1 (7.1) | 0 | 0 | 3 (21.4) | 2 (14.3) | 1 (7.1) |
| Rotellar et al.\(^{[19]}\) | 5 | 67 | PBC (20) Alcohol (20) HCC (60) | 10 | 1.14 | 3 (60.0) | 1 (20.0) | 0 | 0 | NR | 0** | NR |
| Brustia et al.\(^{[20]}\) | 8 | NR | Bile atresia (12.5) HCC (12.5) PBC (25.0) Secondary biliary cirrhosis (12.5) Chronic rejection (12.5) Others (25.0) | NR | NR | NR | NR | NR | NR | NR | NR | NR |
| Troisi et al.\(^{[21]}\) | 4 | 41 | PSC (50) Toxic cholestatic hepatitis (25) HCC (25) | 14 | 0.65 | 0 | 1 (25.0) | 0 | 0 | 1 (25.0) | 0 | 1 (25.0) |

*Both portal vein and outflow issues mentioned together in these studies, **Two reported deaths were 4 and 9 months post-transplant. GRWR: Graft recipient weight ratio, HAS: Hepatic artery stenosis, HAT: Hepatic artery thrombosis, HBV: Hepatitis B virus, HCC: Hepatocellular carcinoma, HCV: Hepatitis C virus, MELD: Model for end-stage liver disease, NR: Not reported, PBC: Primary biliary cirrhosis, PSC: Primary sclerosing cholangitis, PVS: Portal vein stenosis, PVT: Portal vein thrombosis, PLDH: Pure laparoscopic donor hepatectomy

### Table 6: Summary of the meta-analysis comparing pure laparoscopic donor hepatectomy with open donor hepatectomy

| Outcomes | Number of studies | Number of PLDH patients | Number of ODH patients | OR/SMD (95% CI) | \( P \) | I\(^2\) (%) |
|----------|-------------------|-------------------------|------------------------|-----------------|-----|----------|
| Estimated blood loss [Figure 2a] | 4 | 361 | 626 | -106.93 (-215.64–1.78) | 0.05 | 89 |
| Length of hospital stay [Figure 2b] | 5 | 366 | 636 | -0.73 (-1.34–0.12) | 0.02 | 74 |
| Overall morbidity [Figure 2c] | 5 | 366 | 636 | 0.70 (0.47–1.03) | 0.07 | 0 |
| Major complications [Figure 2d] | 5 | 366 | 636 | 1.13 (0.34–3.81) | 0.84 | 0 |
| Operative time [Figure 2e] | 6 | 386 | 656 | 29.15 (8.53–49.77) | 0.006 | 60 |

ODH: Open donor hepatectomy, PLDH: Pure laparoscopic donor hepatectomy, OR: Odds ratio, SMD: Standardised mean difference, CI: Confidence interval
Living donors are healthy individuals who voluntarily submit to major surgery with potential morbidity and mortality and hence, the primary concern should focus on the donors’ safety. Almost 30-50% of the complications following living donor hepatic lobectomy are related to the extent of the abdominal incision including incisional hernia, chronic abdominal discomfort, slow rehabilitation and delayed functional recovery.萨姆斯坦等报告了PLDH和开放组在腹壁相关并发症的较低发病率（4% vs. 16%）。实施微创肝脏手术作为供肝切取术可能潜在地降低外科创伤、相关手术切口并发症并增强术后恢复而不增加围手术期的发病率。

开发一个PLDH项目需要在先进的腹腔镜肝脏手术方面和标准供肝切取术方面有经验。纯腹腔镜手术应遵循标准手术原则。手辅助或混合技术在供肝切取术中已被很好地描述，并在一些中心被逐步引入以降低供肝风险和发病率。手辅助供肝切取术或混合方法减少了供肝切口而允许直接控制和手动处理肝脏。然而，助手的手限制了术中的内窥视图和视野。

图2：森林图（a-e）显示了纯腹腔镜供肝切取术和开放供肝切取术之间的 meta-分析结果。

The development of a PLDH program requires experience in both advanced laparoscopic liver surgery and standard open donor hepatectomies. The pure laparoscopic approach should follow the principles of the standard open technique. Hand-assisted or hybrid techniques for donor hepatectomy have been well described and in some centres this has been adopted as a stepwise evolution to reduce donor risk and morbidity. Hand-assisted donor hepatectomy or the hybrid approach minimises the donor wound incision while allowing direct control and manual handling of the liver. However, the assistant’s hand limits the intra-operative views and the exposure.

The evaluation process and selection criteria for living donation should be the cornerstone of every LDLT program and a thorough donor assessment cannot be overemphasised. As PLDH is at an embryonic stage, further donor selection criteria have been introduced to ensure the safety and success of this new approach. In the laparoscopic approach, mobilisation, manipulation and handling of the liver can be challenging and therefore, ideally, estimated graft weight should be low.

Implementation of new technology is a key aspect and should be integrated in the new approach of PLDH. The use of a 3D flexible camera provides a better view of the posterosuperior segments of the liver and great perception of depth, especially when performing major liver surgery with large and deep cut surfaces. In addition, the use of 3D camera facilitates suturing and reconstruction. Indocyanine green (ICG) infrared fluorescence camera offers direct visualisation of the extra-hepatic bile duct and helps to define the exact site of division the bile duct at the level of the hilum to allow for accurate division. The combination of an ICG infrared camera and real-time cholangiography could potentially decrease the risk of biliary complications such as biliary stricture, as well as the incidence of multiple ducts in the graft.
The use of the Pringle maneuver during donor hepatectomy remains controversial. Almost all liver transplant centres perform open donor hepatectomies in LDLT without applying inflow occlusion for fear of ischemia-induced graft injury.[38] Imamura et al. have shown that inflow occlusion, total or selective (arterial or portal), is safe and can be applied to living donor hepatectomies without causing graft injury. Even though the effect on reducing blood loss was not significant, inflow occlusion enabled a meticulous and precise liver resection avoiding anatomical complications.[46] The use of the Pringle manoeuvre during laparoscopic donor hepatectomies for adult LDLT has been more liberal. In four out of nine studies included in our review, selective Pringle manoeuvre was used during parenchymal transection without compromising the graft and recipient outcomes.

In our review, we have shown that PLDH for adult LDLT is safe and technically feasible when performed in highly specialised centres and with carefully selected donors. The conversion rate was <3% with zero mortality and overall morbidity. All major complications noted were classified as CD 3b (2.8%). There was a trend towards lower overall morbidity in the pure laparoscopic group that did not reach statistical significance [Figure 2c]. There was no difference between the PLDH and ODH groups in terms of estimated blood loss, overall morbidity and major complications. However, the LOS was significantly shorter in the PLDH group. The potential benefits of PLDH including wound morbidity and faster recovery could increase the willingness of potential donors to donate in LDLT. Further development and standardisation of the technique are important in moving towards wider acceptance of this technique. In cases where the PLDH was used without any selection criteria, the incidence of later biliary problems (stricture or leakage) was significantly higher (21% vs. 39%).[39]

Limitations of our study include the paucity of published data and the lack of high-level, good quality comparative studies between open and PLDH for adult LDLT. The majority of the studies are from highly experienced centres of the Eastern world including Korea, Japan and China, with established programs of adult LDLT. In fact, 88% of the included patients in our study came from South Korea where PLDH for adult LDLT has been widely implemented.[14] Despite this being the largest multicenter experience, it did not consider the different selection criteria among the 5 centres. The number of rest-reported case series is too small to validate the safety and reproducibility of the technique. Extrapolation of those results to the rest of the world may not be easily applicable. The promising recent results although encouraging leaves no doubt that there may be a steep learning curve in the adoption of this new technique. In the propensity score-matched analysis of Hong et al., the PLDH group included patients operated after March 2016, excluding the initial cases done to accumulate experience.[39] Moreover, our study included cases of PLDH for adult LDLT, excluding other minimally invasive approaches, hand-assisted and hybrid techniques. Comparisons were only made between pure laparoscopic and ODH as that is currently the standard practice. Potential benefits of hand-assisted, or hybrid techniques or robotics have not been investigated. With the advances in technology, the future could be that the living donor hepatectomies are performed using the robotic approach and perhaps reducing the learning curve.[47]

Future comparative studies should focus on the functional recovery, return to work and quality of life of individuals undergoing laparoscopic donor hepatectomy.

CONCLUSIONS

Our systematic review results show PLDH for adult LDLT is a safe and feasible procedure when performed in highly specialised centres. Importantly, in terms of donor safety, peri-operative outcomes of PLDH are similar to the standard open approach, with lesser blood loss for the former and shorter operative time for the latter. Long-term results on the functional recovery of donors undergoing PLDH are awaited and would perhaps support the use of the technique in the future. Careful donor selection and standardisation of the technique are imperative for the successful implementation and adoption of the procedure worldwide.

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Conflicts of interest
There are no conflicts of interest.

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Supplementary Figure 1: (a) Funnel plot for pure laparoscopic donor hepatectomy versus open donor hepatectomy for estimated blood loss. (b) Funnel plot for pure laparoscopic donor hepatectomy versus open donor hepatectomy for length of stay. (c) Funnel plot for pure laparoscopic donor hepatectomy versus open donor hepatectomy for overall morbidity. (d) Funnel plot for pure laparoscopic donor hepatectomy versus open donor hepatectomy for major complications. (e) Funnel plot for pure laparoscopic donor hepatectomy versus open donor hepatectomy for operative time.