Received: 23 January 2022 | Accepted: 28 February 2022

DOI: 10.1111/ctr.14681

Clinical TRANSPLANTATION
The Journal of Clinical and Translational Research
WILEY

REVIEW ARTICLE

Which cava anastomotic techniques are optimal regarding immediate and short-term outcomes after liver transplantation: A systematic review of the literature and expert panel recommendations

Tamer M. Shaker[1] | James D. Eason[2] | Brian R. Davidson[3] | Rolf N. Barth[4] | Jacques Pirenne[5,6] | Oscar Imventarza[7] | Michael Spiro[8,10] | Dimitri Aristotle Raptis[9,10] | John Fung[4] | On behalf of the ERS4OLT.org Working Group: Claus Niemann, San Francisco, CA, USA, Joerg-Matthias Pollok, London, UK, Marina Berenguer, Valencia, Spain, Pascale Tinguely, London, UK, Manikandan Kathirvel, London, UK, Nolitha Morare, London, UK.

[1]Division of Transplant, Department of Surgery, University of Minnesota, Minneapolis, Minnesota, USA

[2]James D. Eason Transplant Institute, University of Tennessee, Memphis, Tennessee, USA

[3]UCL Division of Surgery & Interventional Science, University College London, Royal Free Campus, Rowland Hill Street, London, United Kingdom of Great Britain and Northern Ireland

[4]Department of Surgery, Transplantation Institute, University of Chicago, Chicago, Illinois, USA

[5]Department of Microbiology, Immunology, and Transplantation, Lab of Abdominal Transplantation, Transplantation Research Group, KU Leuven, Leuven, Belgium

[6]Department of Abdominal Transplantation Surgery and Coordination, University Hospitals of Leuven, Leuven, Belgium

[7]Liver Transplant Unit, Hospital Argerich, Hospital Garrahan, Stalyc Representative, Buenos Aires, Argentina

[8]Department of Anesthesia and Intensive Care Medicine, Royal Free Hospital, London, UK

[9]Clinical Service of HPB Surgery and Liver Transplantation, Royal Free Hospital, London, UK

[10]Division of Surgery & Interventional Science, University College London, London, UK

Correspondence
Tamer M. Shaker, Department of Surgery, Division of Transplantation, University of Minnesota, 420 Delaware St SE, MMC 195, Minneapolis, MN 55455, USA
Email: shak0021@umn.edu

This work was conducted in preparation for the ILTS - ERAS4OLT.org Consensus Conference on Enhanced Recovery for Liver Transplantation, January 2022, Valencia, Spain.

Protocol registration: CRD42021240979.

Funding information
This manuscript was prepared for the ERAS4OLT.org Consensus Conference 2022, which is partially funded by the International Liver Transplant Society (ILTS).

Abstract

Background: It has long been debated whether cava anastomosis should be performed with the piggyback technique or cava replacement, with or without veno-venous bypass (VVB), with or without temporary portocaval shunt (PCS) in the setting of liver transplantation.

Objectives: To identify whether different cava anastomotic techniques and other maneuvers benefit the recipient regarding short-term outcomes and to provide international expert panel recommendations.

Data sources: Ovid MEDLINE, Embase, Scopus, Google Scholar, and Cochrane Central.

Methods: A systematic review following PRISMA guidelines and recommendations using the GRADE approach derived from an international expert panel (CRD42021240979).

Results: Of 3205 records screened, 307 publications underwent full-text assessment for eligibility and 47 were included in qualitative synthesis. Four studies were randomized control trials. Eighteen studies were comparative. The remaining 25 were single-center retrospective noncomparative studies.

Conclusion: Based on existing data and expert opinion, the panel cannot recommend one cava reconstruction technique over another, rather the surgical approach should be based on surgeon preference and center dependent, with special consideration toward patient circumstances (Quality of evidence: Low | Grade of Recommendation: Strong). The panel recommends against routine use of vevo-venous bypass (Quality of evidence: Very Low | Grade of Recommendation: Strong) and against the routine use of temporary porto-caval shunt (Quality of evidence: Very Low | Grade of Recommendation: Strong).

KEYWORDS
caval replacement, cavocavostomy, liver transplantation, piggyback technique, renal function, temporary portocaval shunt, venovenous bypass

1 | INTRODUCTION

The initially described conventional orthotopic liver transplantation (OLT) involves resection of the recipient native liver along with the retrohepatic inferior vena cava (IVC), followed by the implantation of a whole deceased donor liver graft with the interposed donor IVC. Tzakis et al. in 1989 first described the piggyback (Pb) technique, which preserves the recipient IVC and intended to remove the need for veno-venous bypass.[1,2] The piggyback technique has had several iterations, including the use of the three hepatic veins and the development of the side-to-side cavo-cavostomy.[3,4]

1.1 | Function and use of veno-venous bypass during liver transplant

During the classic OLT procedure, simultaneous complete occlusion of the recipient IVC and portal vein can lead to hemodynamic instability. As a result, venovenous bypass (VVB) was developed to allow diversion of blood from the recipient IVC and portal vein directly to the patient's superior vena cava during the anhepatic phase, using heparin-bonded cannulae and a motor-driven bypass system.[5,6] VVB can be used either routinely or selectively in patients showing hemodynamic instability after a trial of clamping the IVC and portal vein, prior to explanting of the recipient's liver. Outcome analysis of venous reconstruction technique therefore has to consider whether VVB bypass was utilized.

1.2 | Use of temporary portocaval shunts

Temporary portocaval shunt (PCS) was first described by Tzakis et al. in 1993.[7] An end-to-side anastomosis is formed between the recipient's portal vein and infrahepatic IVC; it is used as an alternative to VVB in piggyback OLTs, to allow for decrease in portal venous pressure and decreased congestion of the splanchnic bed, and intestinal edema.

1.3 | Previous reviews

There has previously been an attempt to compare transplant outcomes related to the technique of venous reconstruction. A systematic review was performed comparing the benefits and harms of piggyback technique to the conventional liver transplant concluded that they could not recommend nor refute the use of the piggyback technique.[8] Similarly, a systematic review comparing the benefits and harms of VVB could not support or refute the use of VVB in liver transplantation.[9]

An international survey of the practice of performing deceased donor OLT was conducted by Kluger and coworkers and reported in 2011. This survey, Survey of Adult Liver Transplantation (SALT), encompassed 50 centers in Europe, eight centers in North America, two in South America, one in South Africa, and three in the Middle East. Of note was that preservation of the IVC (for piggyback implantation) was the most frequently used technique, being used routinely by 57% of the teams and selectively by 38%. Venous bypass was used in 15% of cases of IVC preservation and in 58% when the IVC was resected.[10] No outcome analysis was performed.

It has long been debated whether caval anastomosis in liver transplantation should be performed with the piggyback technique or caval replacement, with or without VVB, with or without temporary PCS, regarding any potential short-term benefits to the recipient, such as mortality or morbidity, including renal dysfunction.

1.4 | Aim of the review

In this manuscript, we have reviewed the published literature on short term outcomes of liver transplant related to the method of venous

reconstruction with the goal of delineating recommendations based on the existing data and the expert opinion of the panel. Additionally, we aim to compare patients that underwent VVB versus no VVB and temporary PCS versus no PCS.

2 | METHODS

2.1 | Protocol and registration

The study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta–Analyses (PRISMA) guidelines. The protocol was registered on PROSPERO (CRD42021240979).

2.2 | Eligibility criteria

The search terms were organized according to the PICO (population, intervention, control, and outcomes) criteria. The population represents adult (aged 18 years and older) recipients who received deceased donor. Recipients of split-liver grafts were excluded. Studies that that reported on pediatric population alone, case reports or published in language other than English were also excluded. The intervention groups included patients that received a piggy back cava anastomosis, a PCS, or VVB. The control groups included patients that received a cava replacement. Results from the studies were not verified. The main aim was to compare data from randomized controlled trials and to perform metanalysis. However, comparative and single cohort studies were also included, retrospective or prospective, if transplant outcome data was available.

2.3 | Outcomes

The main outcomes were operative duration, blood transfusion requirements. Additional outcomes were mortality, renal function, and complications post-transplantation as well as hospital stay.

2.4 | Information sources

A systematic literature review was performed on March 15, 2021, searching the online databases, including Ovid MEDLINE, Embase, Scopus, Google Scholar, Clinical.Trials.gov, and the Cochrane Central Register of Controlled Trials. Both cava anastomotic techniques and surgical shunts/VVB were included. There were no publication year limitations. Studies reporting on pediatric populations as well as case reports or conference abstracts were excluded.

2.5 | Search

The following keywords were used in various combinations: ("cava reconstruction techniques" OR "cava anastomosis" OR "cava replacement" OR "cava resection" OR "conventional technique" OR "piggy- back" OR "piggy back" OR "veno-venous bypass" OR "venovenous bypass" OR "porto-caval shunt" OR "portocaval shunt") AND ((liver OR hepatic) AND (transplant OR transplantation))

2.6 | Study selection

Bibliographic searches were performed by professional academic librarians from the University of Zurich. Record screening was performed by two independent authors while all authors determined eligibility for each full text article using predefined criteria. Disagreements were resolved by consensus.

2.7 | Quality of studies and recommendations grading

The "Grading of Recommendations Assessment, Development and Evaluation" (GRADE) approach was used for grading quality of evidence and strength of recommendations.[11] The GRADE system was designed to provide a comprehensive and structured approach to rating the quality of evidence (QOE) for systematic reviews, and to grade the strength of recommendations for development of guidelines in health care. We applied the modified GRADE approach for QOE assessment derived from systematic reviews using estimates summarized narratively.[12] The QOE was rated separately for each outcome. The direction and strength of recommendation was assessed individually by all authors and disagreements resolved by consensus.[13,14]

3 | RESULTS

3.1 | Study selection

Of 3205 records screened, 307 publications underwent full-text assessment for eligibility and 47 were included in qualitative synthesis. Two hundred sixty articles were excluded, 164 were inappropriate with regards to study outcomes, 20 were case reports, 68 did not have full texts, and eight had no English text (**Figure 1**). Four studies were randomized control trials (RCTs). Eighteen studies were comparative cohorts. The remaining 25 were single-center retrospective noncomparative studies. Baseline characteristics, including study type, number of subjects enrolled, and target outcomes, are reported in Table 1.

3.2 | Study characteristics

The study characteristics are listed in Table 1.

3.3 | Results of individual studies

The results of the individual studies as reported by the study authors are listed in Table 2.

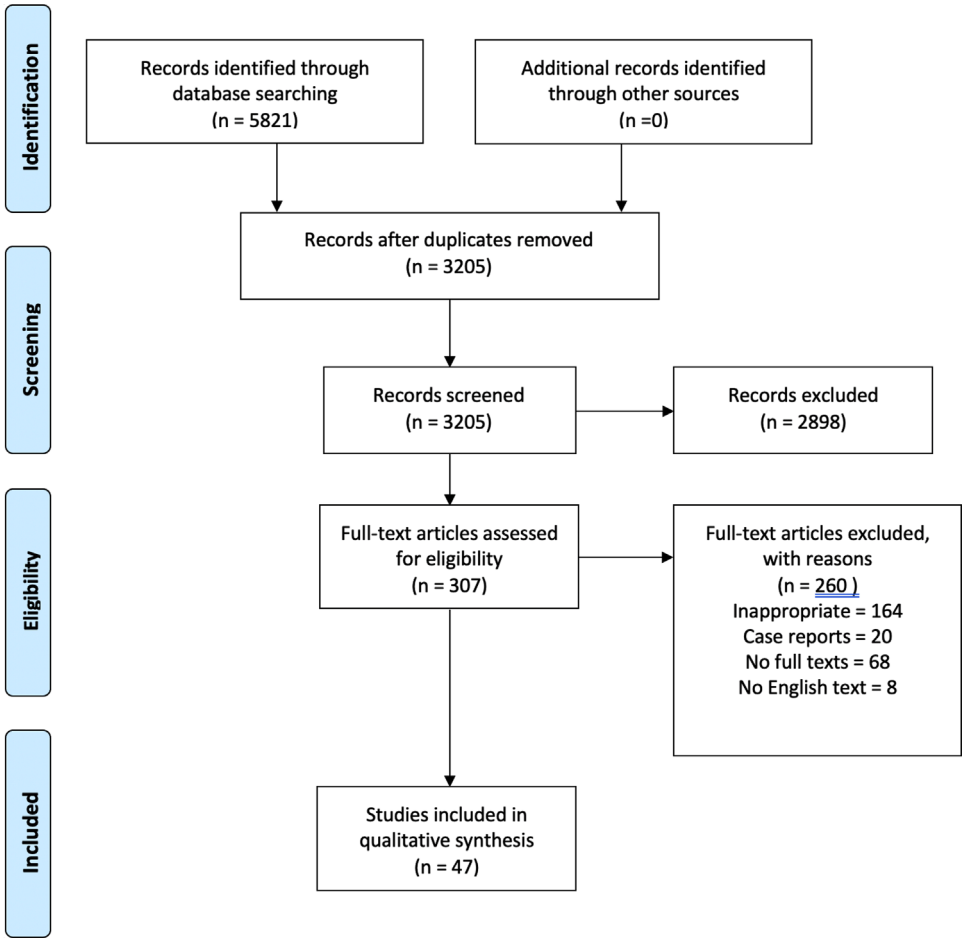

FIGURE 1 Flow diagram of study extraction and selection

3.4 | Operation duration in cava replacement versus piggyback technique

The majority of the 16 observational comparative studies[17,18,19,22,23,31,33,40,43,44,48,51,53,55,58,59] and two RCTs[5,32] demonstrated that the operation duration in the piggyback group was less than that of the cava replacement group. No studies demonstrated a shorter operative time in the cava replacement group. The quality of evidence rating was low. Despite the presence of RCTs, RCTs were from 1997 and 2004, consisted of 39 and 67 patients at single centers, the RCTs were dated and underpowered for the immediate and short-term outcomes of interest.[5,32]

3.5 | Units of packed red blood cells transfused intraoperatively in cava replacement versus piggyback technique

The majority of the 18 observational comparative studies[17,18,19,22,23,31,33,36,40,43,44,48,51,53,54,55,58,59] and two RCTs[5,32] demonstrated that the units of PRBCs transfused in the piggyback group was fewer than that of the cava replacement group. No studies demonstrated the units of PRBCs transfused in the cava replacement group was fewer. The GRADE quality of evidence rating was low.

3.6 | Early postoperative mortality in cava replacement versus piggyback technique

All of the nine observational comparative studies[17–19,27,33,36,40,53,58] and two RCTs[5,32] demonstrated that there was no difference in early postoperative mortality in the piggyback group and that of the cava replacement group, except for one study that showed piggyback group with less early postoperative mortality rate.[58] The GRADE quality of evidence rating was low.

3.7 | Postoperative renal dysfunction in cava replacement versus piggyback technique

The majority of the 14 observational comparative studies[17,19,21,27,31,33,40,43,48,51,53,54,58,59] and one RCT[3] demonstrated that the there was no difference in postoperative renal dysfunction in the piggyback

TABLE 1 Study characteristics

	Study type	No. of patients	Main outcomes assessed
Arzu,[15] 2008	Single-center, retrospective, comparative OLT PCS, Pb vs. No PCS, Pb	N = 186 (PCS, Pb N = 97 No PCS, Pb N = 89)	• Operative duration • Creatinine post op day 3 • Blood Loss • 1,3,12-month survival • Hospital LOS • CI/LVEF
Audet,[16] 2009	Single-center retrospective Single-center experience with OLT Pb	N = 423	• Operative duration • pRBCs given • 1-year survival • Surgical complications • In hospital mortality
Barbas,[17] 2018	Single-center retrospective, comparative CI vs. Pb vs. SS	N = 1233 (CI N = 1076 Pb N = 92 SS N = 65)	• Operative duration • pRBCs given • 1-year survival, 90-day mortality • Peak creatinine • 90-day graft failure rate • Vasopressin use • Hospital LOS • Complication rate (Clavien-Dindo > / = 3b)
Barshes,[18] 2004	Single center retrospective, comparative CI vs. Pb in OLT	N = 220 (CI N = 98 Pb N = 122)	• 1,3-year survival; 90-day mortality • Operative duration • PRBCs given • LOS • complications
Brescia,[19] 2015	Prospective randomized control, single-center Randomized control trial CI, VVB vs. Pb	N = 32 (CI, VVB N = 15 Pb N = 17)	• Operative duration • pRBCs given • Estimated marginal mean creatinine • Presence of severe ARF first 28 days Postop • 90-day mortality, 1-year survival • Postop Ascites development • Frequency of venous outflow obstruction
Busque,[20] 1998	Single-center retrospective, not comparative Single-center, Pb with conversion to CI	N = 131 (CI (converted from Pb) N = 33 Pb N = 81)	• Operative duration • Blood transfused • Estimated marginal mean creatinine • max postop serum creatinine levels • ICU/Hospital LOS • Postop mortality
Cabezuelo,[21] 2003	Single-center retrospective Pb vs. CI, VVB vs. CI, No VVB	N = 184 (CI, VVB N = 20 CI, No VVB N = 84 Pb N = 80)	• Incidence Early Acute Renal Failure • PRBC requirements • Intraoperative complications • Postreperfusion syndrome
Carvalho,[22] 1999	Single-center retrospective CI, VVB (ad hoc) vs. Pb	N = 51 (CI, VVB N = 24 Pb N = 27)	• Operative duration • pRBCs given • LOS • Operative mortality • Incidence of respiratory failure • Incidence of pulmonary infiltrates
Chan,[23] 2017	Retrospective, provincial transplant database, comparative Comparison of three caval reconstruction techniques	N = 200 (CI N = 58 Pb N = 72 SS N = 70)	• Operative time • Blood loss • 1-year mortality, in hospital mortality • ICU, Hospital LOS • Complications: HV, PV, HA thrombosis

(Continues)

TABLE 1 (Continued)

	Study type	No. of patients	Main outcomes assessed
De Cenarruzabeitia,[24] 2007	Single-center retrospective Advantage to PCS, Pb to No PCS, Pb	N = 401 (PCS, Pb N = 356 [High portal flow N = 162 Low portal flow N = 194] No PCS, Pb N = 45 [High portal flow N = 11 Low portal flow N = 34]	• Operation duration • Postoperative creatinine (high portal flow vs. low) • pRBCs given (high portal flow vs. low)
Figueras,[25] 2001	Single-center prospective randomized control trial Temporary PCS, Pb-prospective randomized study	N = 80 (PCS, Pb N = 40 No PCS, Pb N = 40)	• pRBCs given • Operative duration • Creatinine post-op day 3
Fleitas,[26] 1994	Single-center prospective case series 44 consecutive Piggyback technique	N = 44	• Operative duration • Total blood product requirement • 90-day, 1-year survival
Ghazaly,[27] 2014	Single-center retrospective CI vs. Pb	N = 120 (CI N = 93 Pb N = 27)	• Short term dialysis • Complications • 90-day mortality • 3 months, 1-year graft survival • Quality of life at 3, 12 months
Ghinolfi,[28] 2011	Single-center retrospective PCS	N = 148 (PCS, Pb N = 58 No PCS, Pb N = 90)	• pRBCs given • 90-day, 1-year survival • 90-day, 1-year graft loss • Operative duration
Grande,[29] 1996	Prospective randomized control trial Randomized control trial for VVB in OLT	N = 77 (VVB = 38 No VVB = 39)	• pRBCs given • Serum creatinine level at post-op day 7 • Need for hemodialysis
Hesse,[30] 1997	Single-center retrospective Single-center, SS with none, VVB or PCS	N = 54 (SS N = 38 SS, VVB N = 8 SS, PCS N = 8)	• Operative duration • pRBCs given • change in Creatinine • ICU LOS
Hesse,[31] 2000	Single-center retrospective Single-center experience with CI, Pb, SS	N = 162 (CI N = 75 Pb N = 15 SS N = 72)	• Operative time • pRBCs given • highest cr POD0-7 • ICU LOS • Complications: PV, HA thrombosis, Ascites postop • 12-month survival
Isern,[32] 2004	Single-center, Prospective randomized control trial Randomized control trial for CI, VVB vs. Pb, VVB	N = 67 (CI, VVB N = 34 Pb, VVB N = 33)	• pRBCs given • Operative duration • 30-day mortality • Hospital LOS • Duration of mechanical ventilation
Jovine,[5] 1997	Single-center, prospective randomized control trial Randomized control trial for CI, VVB vs. Pb, VVB	N = 39 (CI, VVB N = 19 Pb, VVB N = 20)	• pRBCs given • Operative duration • Renal failure • Vascular complications • Graft nonfunction • Postoperative morbidity, mortality
Khan,[33] 2006	Single-center retrospective SS vs. CI, VVB	N = 384 (CI, VVB N = 138 SS N = 246[No PCS N = 54 PCS N = 192])	• pRBCs given • Operative duration • Serum creatinine level post-op day 3 • Long-term survival, 30-day mortality • Ventilator support • ICU, Hospital LOS • Complications: HA thrombosis, PNF

(Continues)

TABLE 1 (Continued)

	Study type	No. of patients	Main outcomes assessed
Kim,[34] 2018	Single-center retrospective Single center divided 300 cases into three groups by order of operation date	N = 242 (Group 1: First 100 N = 81 Group 2: 101–200 LT N = 78 Group 3: 201–300 LT N = 83)	• pRBCs given • Operative duration
Kuo,[35] 1995	Single-center retrospective VVB vs. No VVB in CL	N = 31 (VVB N = 20 No VVB N = 11)	• Overall survival (time period not specified) • Peak creatinine (14 days postop) • Operative time • pRBCs given • degree of weight gain • ICU, Hospital LOS
Lerut,[36] 1997	Single-center retrospective Single-center experience with CI, VVB vs Pb vs Pb, VVB	N = 116 (CI, VVB N = 38 Pb, VVB N = 39 Pb, no VVB N = 39)	• pRBCs given • 90-day, 1-year survival • Peak ALT • 90-day re-OLT • PNF • Need for postop HD
Lerut,[37] 2003	Single-center retrospective Single-center experience with SS, no VVB	N = 202	• 3-month, 1-year survival • Operation duration • Blood loss • ICU, Hospital LOS • De Novo Post OLT renal support • Vascular complications
Levi,[38] 2012	Single-center retrospective review comparing two eras for Pb Comparison of two eras for Pb	N = 2000 (Era 1 6/94-5/02 N = 1080 Era 2 6/02-10/10 N = 920)	• Operation duration • pRBC given • 30-day mortality, 1-year survival • Hospital LOS
Mangus,[39] 2007	Single-center retrospective PGB	N = 526	• 3-month, 1-year survival • 3-month, 1-year graft survival • Hospital LOS • PRBCs given
Margarit,[40] 1994	Single-center retrospective CI, VVB vs. CI, no VVB vs. Pb	N = 119 (CI, VVB N = 32 CI, No VVB N = 24 Pb N = 63)	• Operative duration • Post-op serum creatinine • pRBCs given • 30-day mortality
Margarit,[41] 2005	Single-center retrospective PCS, Pb vs. No PCS, Pb	N = 111 (PCS, Pb N = 57 No PCS, Pb N = 54)	• Operative duration
Mehrabi,[42] 2009	Single-Center Retrospective SS	N = 500	• PRBCs given • Operative duration • Complications • 30, 90-day mortality • Hospital, ICU LOS
Miyamoto,[43] 2004	Single-center retrospective CI vs. Pb	N = 167 (CI N = 96 Pb N = 71)	• 1 year survival • Operative time • pRBCs given • Change in creatinine • Complications • ICU LOS • Reinterventions
Moreno-Gonzalez,[44] 2003	Single-center retrospective Pb vs. CI, VVB vs. CI, No VVB	N = 50 (Pb N = 17 CI, VVB N = 16 CI, No VVB N = 17)	• Operative duration • pRBCs given • postoperative complications • reoperations • retransplantation • operative mortality

(Continues)

TABLE 1 (Continued)

	Study type	No. of patients	Main outcomes assessed
Mossdorf,[45] 2015	Single-center retrospective Single-center experience with VVB	N = 163	• Operative duration • pRBCs given • 30-day mortality, 1-year survival • Creatinine post-op day 3 • Bypass-related complications
Muscari,[46] 2005	Single-center retrospective Single-center experience with PCS, Pb	N = 156	• Operative time • pRBCs given • early complications • early mortality
Nacif,[47] 2020	Single-center retrospective CI, No VVB vs. Pb, No VVB	N = 999 (PCS, Pb N = 509 No PCS, Pb N = 490)	• pRBCs given • Post-op day 3 serum creatinine level • 1-year survival • Operative duration • Complication rate
Nishida,[48] 2006	Single-center retrospective chart review CI vs Pb	N = 1067 (CI N = 149 Pb N = 918)	• Operative duration • Serum creatinine level at post-op day 3 • Blood requirement • 1-year survival • ICU, Hospital LOS
Pratschke,[49] 2012	Single-center retrospective Is PCS useful?	N = 448 (PCS, Pb N = 274 No PCS, Pb N = 174)	• Blood loss • Serum creatinine level at post-op day 7 • Mean survival
Rayar,[50] 2017	Single-center retrospective review with propensity score matching PCS in OLT propensity score analysis	N = 686 (PCS, SS N = 343 No PCS, SS N = 343)	• pRBCs given • 1-year survival • Operative time • Complications • ICU, Hospital LOS
Reddy,[51] 2000	Single-center retrospective Pb vs. CI, Pb with selective use of VVB	N = 76 (CI N = 40 Pb N = 36)	• pRBCs given • Creatinine post-op day 3 • Operative duration • 1-year survival • ICU, Hospital LOS • Hospital charges
Remiszewski,[52] 2006	Single-center retrospective Pb vs. CI	N = 100 (CI N = 50 Pb N = 50)	• 1-year survival • Postoperative complications • Hospital LOS • POD 10 AST/ALT/total Bilirubin
Sakai,[53] 2010	Single-center retrospective CI, VVB vs. Pb, VVB vs. Pb, No VVB	N = 426 (CI, VVB N = 104 Pb, VVB N = 148 Pb, No VVB N = 174)	• pRBCs given • Incidence of AKI, ARF • Operative duration • 30-day, 1-year survival • HA thrombosis • RE-exploration • ICU, Hospital LOS • Intraoperative complications
Schmitz,[54] 2014	Single-center retrospective CI, VVB vs. CI, No VVB vs. SS	N = 414 (SS N = 176 CI N = 238 [VVB N = 112 No VVB N = 126])	• Renal function • pRBCs given • Complications: Biliary, vascular, infectious
Shokouh-Amiri,[55] 2000	Single-center retrospective Single-center experience with CI, VVB vs. Pb	N = 90 (CI, VVB N = 56 Pb N = 34)	• Operative duration • pRBCs given • 1-year survival • ICU, Hospital LOS • Hospital charges

(Continues)

TABLE 1 (Continued)

	Study type	No. of patients	Main outcomes assessed
Suarez-Munoz,[56] 2006	Single-center retrospective PCS	N = 349 (PCS, Pb N = 160 No PCS, Pb N = 189)	• Operative duration • Creatinine (maximum immediate post-op serum level) • Recovered RBCs • ICU, Hospital LOS
Sun,[57] 2017	Single-center retrospective with propensity score matching Cl, VVB vs. Cl, no VVB	N = 442 (Cl, VVB N = 221 Cl, No VVB N = 221)	• Operative duration • AKI incidence • pRBCs given • 1-year mortality
Vieira de Melo,[58] 2011	Single center retrospective, comparative Cl, No VVB vs. Pb, No VVB	N = 195 (Cl, No VVB N = 125 Pb, No VVB N = 70)	• Operative duration • 30-day, 1-year mortality • POD 3 Cr • pRBCs given • Biliary, vascular, infectious complications • ICU, Hospital LOS
Widmer,[59] 2018	Single-center retrospective, comparative Cl vs. Pb	N = 378 (Cl N = 201 Pb N = 177)	• Operative duration • pRBCs given • AKI incidence • 5-year survival • ICU, Hospital stay • Complication rate
Wu,[60] 2001	Single-center retrospective Single-center experience with SS	N = 115 (SS, no VVB N = 54 SS, VVB N = 61)	• 1-year survival • Maximum post-op serum creatinine in the first 5 days • Operative duration • pRBCs given • ICU, Hospital LOS

Cl- Classic caval resection, VVB-venovenous bypass, SS-side to side cavocavostomy, LOS-length of stay, PCS-portocaval shunt, POD-postoperative day, ICU-intensive care unit, Pb-Piggyback technique, pRBCs-packed red blood cells, AKI-acute kidney injury, OLT-orthotopic Liver transplant, ALT- alanine transaminase, AST-aspartate aminotransferase, NS-not significant, NA-not applicable.

group versus that of the cava replacement group. The GRADE quality of evidence rating was low.

3.8 | Early complications in cava replacement versus piggyback technique

The majority of the 14 observational comparative studies[17,23,27,31,33,43,44,48,52–54,58,59] and one RCT[3] demonstrated that there was no difference in the early complication rate in the piggyback group versus that of the cava replacement group. The GRADE quality of evidence rating was low.

3.9 | Hospital length of stay in cava replacement vs piggyback technique

The majority of the 13 observational comparative studies[17,18,22,23,27,33,48,51,52,53,55,58,59] and one RCT[32] demonstrated that the there was no difference in the hospital LOS in the piggyback group versus that of the cava replacement group. The GRADE quality of evidence rating was low.

3.10 | Operative duration in VVB versus no VVB

The majority of the seven observational comparative[30,35,40,44,51,53,57] demonstrated that the operative duration in the no VVB group was less than that of the VVB group. The quality of evidence rating was very low.

3.11 | Units of packed red blood cells transfused intraoperatively in VVB versus no VVB

The majority of the nine observational comparative studies[30,35,36,40,44,51,53,54,57] and one RCT[29] demonstrated that the units of PRBCs transfused in the no VVB group was fewer than that of the VVB group. The GRADE quality of evidence rating was low.

3.12 | Early postoperative mortality in VVB versus no VVB

All of the three observational comparative studies[36,40,53] demonstrated that there was no difference in early postoperative mortality

in the no VVB group and that of the VVB group. The GRADE quality of evidence rating was very low.

3.13 | Postoperative renal dysfunction in VVB versus no VVB

The majority of the nine observational comparative studies[21,30,35,40,51,53,54,57,60] and one RCT[29] demonstrated that the there was no difference in postoperative renal dysfunction in the no VVB group versus that of the VVB group. The GRADE quality of evidence rating was low.

3.14 | Early complications in VVB versus no VVB

The majority of the three observational comparative studies[44,53,54] demonstrated that there was no difference in the early complication rate in the no VVB group versus that of the VVB group. The GRADE quality of evidence rating was very low.

3.15 | Hospital length of stay in VVB versus no VVB

All of the three observational comparative studies[35,51,53] demonstrated that there was no difference in the Hospital LOS in the no VVB group versus that of the VVB group. The GRADE quality of evidence rating was very low.

3.16 | Operation duration in PCS versus no PCS

The majority of the five observational comparative studies[24,28,30,50,56] and one RCT[25] demonstrated that the operative duration in the no PCS group was no different than that of the PCS group. The quality of evidence rating was low.

3.17 | Units of packed red blood cells transfused intraoperatively in PCS versus no PCS

The majority of the six observational comparative studies[24,28,30,49,50,56] and one RCT[25] demonstrated that the PCS group required fewer units of blood transfusion than in the no PCS group. The GRADE quality of evidence rating was low.

3.18 | Early postoperative mortality in PCS versus no PCS

Both of the observational comparative studies[28,50] demonstrated that there was no difference in early postoperative mortality in the no PCS group and that of the PCS group. The GRADE quality of evidence rating was very low.

3.19 | Postoperative renal dysfunction in PCS versus no PCS

The majority of the four observational comparative studies[24,30,49,56] and one RCT[25] demonstrated that the there was no difference in postoperative renal dysfunction in the no PCS group versus that of the PCS group. The GRADE quality of evidence rating was low.

3.20 | Early complications in PCS versus no PCS

Both of the observational comparative studies[24,50] demonstrated that there was no difference in the early complication rate in the PCS group versus that of the no PCS group. The GRADE quality of evidence rating was very low.

3.21 | Hospital length of stay in PCS versus no PCS

One of the two observational comparative studies[56] (n = 349) demonstrated that there was shorter hospital LOS (12.7 vs. 18.9 days, $p = .001$) in the PCS group versus that of the no PCS group, the other study showed no difference.[50] The GRADE quality of evidence rating was very low.

3.22 | Quality of evidence

The main outcomes were identified by the panel as those of prime importance prior to the data analysis. The summary of findings include the early postoperative mortality, operation duration, early complication rate, units of PRBCs transfused, hospital LOS and renal function for caval resection versus piggyback, VVB versus no VVB, and PCS versus no PCS. Additionally, the final QOE grading according to the GRADE approach are summarized in Tables 3A, B, and C.

The QOE was rated low to very low for the reported outcomes dependent on cava anastomotic technique. The main reasons for downgrading were imprecision due to large variation in study groups and interventions as well as limitations due to the retrospective observational nature of most studies. The RCTs that were included were dated and underpowered for the immediate and short-term outcomes we were interested in.

Low quality of evidence despite RCTs secondary to dated trials, underpowered for outcomes of interest, very low quality of evidence for operative duration, mortality, complications, hospital LOS due to only observational comparative studies with low numbers.

TABLE 2 Study outcomes

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Arzu,[15] 2008 OLT PCS, Pb vs. No PCS, Pb	No difference PCS, Pb 504 min No PCS, Pb 511 min, NS	No difference Blood loss PCS, Pb 1239 cc No PCS, Pb 1338 cc, NS	Significantly less survival in No PCS, Pb group (3 month) PCS, Pb 94% No PCS, Pb 88% *P* = .39	No difference Creatinine post-op day 3 PCS, Pb 1.21 No PCS, Pb 1.42 *P* = .133	NA	No difference PCS, Pb 16.5 days No PCS, Pb 17.8 days *P* = .5
Audet,[16] 2009 Single center experience with OLT Pb	Pb 316 min	pRBCs given Pb 3.2 U	In hospital mortality 5.3%	NA	Complication rate 24.2%	NA
Barbas,[17] 2018 CI vs. Pb vs. SS	Significantly less operative time in SS group; no diff between CI and Pb CI 365 ±-179 min Pb 347 ± 88 min SS 321 ± 93 min *P* = .05	No difference pRBCs given CI 4.5 ± 4.6 U Pb 5.3 ± 4.9 U SS 5.2 ± 4.1 U, NS *P* = .10	No difference 90 day mortality CI 4.9% Pb 4.4% SS 3.1%, NS	No difference peak creatinine post op (48 hours) CI 164.5 ±109.0 Pb 159.0 ±97.7 SS 154.4 ± 116.3, NS	No difference in complication rate (Clavien-Dindo > / = 3b) CI-24.7% Pb-31.1% SS- 26.2%, *P* = .4	Increased LOS for Pb group vs other groups CI-13 [9-23] Pb-16.5 [11-34.5] SS- 11 [8.5-29.5] *P* = .009
Barshes,[18] 2004 CI vs Pb in OLT	No difference CI 5 hrs 47 min ± 1 h 3 min Pb 5 h 20 min ± 1 h 18 min, NS	No difference Red cell volume given CI 2.0 (sd 0–6.6) U Pb 2.0 (sd 0 - 5.4) U, NS	No difference 90 day survival CI 96.7% Pb 96.3%, NS	NA	No difference in complication rate in terms of allograft congestion, post OLT ascites	No difference in LOS Pb-7.0 days [0-20.7] CI- 7.0 days [0-20.4], NS
Brescia,[19] 2015 Randomized control trial CI, VVB vs Pb	No difference CI, VVB 724.0 ± 115.3 (555-925) min Pb 649.3 +/- 156.6 (435-960) min, NS *p* = .14	No difference CI, VVB 13.9 +/- 10.3 (4-34) U Pb 9.0 +/- 7.6 (3-35) U, NS *p* = .13	No difference 90-day survival CI 93% Pb 94%, NS *p* = .32	Significantly higher estimated marginal mean for creatinine in CL group CI 2.14 ± .26 Pb 1.47 ± .15 *p* = .02	NA	NA
Busque,[20] 1998 Single-center, Pb with conversion to CI	Not compared Pb 8.6 +/- 1.9 (4.5-14.5) hrs	Not compared pRBCs given Pb 2 (0-18) U	NA	Not compared Maximum serum creatinine level post op day 3 Pb 1.8 +/- 1.5	NA	Not compared Pb- 11 days [7-64]

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Cabezuelo,[21] 2003 Pb vs. CI, VVB vs. CI, No VVB	NA	NA	NA	Significantly less incidence of Acute Renal Failure in Pb group CI, VVB 50% CI, No VVB 39% Pb 18% CI, VVB vs Pb $p < .01$ CI, No VVB vs. Pb $p < .05$	NA	NA
Carvalho,[22] 1999 CI, VVB (ad hoc) vs. Pb	No difference CI, VVB 11.1 ± 2.4 h Pb 11.7 ± 2.4 h, NS	No difference pRBCs given median CI, VVB 6.0 (0-46) U Pb 7.0 (0-56) U, NS	NA	NA	NA	No difference CI-17.5(8-43) Pb- 17.0 (8-186), NS
Chan,[23] 2017 Comparison of three caval reconstruction techniques	Pb significantly shorter CI 366 min Pb 306 min SS 385 min $p < .001$	No difference CI 5995 cc Pb 4641 cc SS 6022 cc, NS	NA	NA	No difference in thrombotic complications (PV, HA, HV)	No difference CI 26.6 ±24.8 days Pb 29.0 ±32.5 days SS 33.6 ±33.8 days
De Cenarruzabeitia,[24] 2007 Advantage to PCS, Pb to No PCS, Pb	No difference High portal flow PCS, Pb 346 +/- 65 min No PCS, Pb 325 +/- 65 min, NS Low portal flow PCS, Pb 332 +/- 80 min No PCS, Pb 335 +/- 70 min, NS	No difference pRBCs given High portal flow PCS, Pb 4.1 +/- 3.1 U No PCS, Pb 6.3 +/- 3.9 U, NS Low portal flow PCS, Pb 4.7 +/- 2.9 U No PCS, Pb 4.7 +/- 2.7 U, NS	NA	No difference Post operative creatinine period High portal flow PCS, Pb 1.1 +/- .4 No PCS, Pb 1.4 +/- 1.0, NS Low portal flow PCS, Pb 1.2 +/- .6 No PCS, Pb 1.5 +/- .8, NS	No difference	NA
Figueras,[25] 2001 Temporary PCS, Pb-prospective randomized study	No difference PCS, Pb 403 +/- 77 min No PCS 387 +/- 56 min, NS	No difference PCS, Pb 2.3 +/- 2.5 U No PCS, Pb 3.3 +/- 2.9 U, NS	NA	No difference between the groups	NA	NA
Fleitas,[26] 1994 Piggyback technique	353 min (215-693 min)	7700 cc (3600-17 600 cc)	90 day survival 81.4%	NA	NA	NA

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Ghazaly,[27] 2014 Cl vs Pb	NA	NA	No difference 90 day survival Cl 100% Pb 100%, NS	No difference Short-term dialysis Cl 13% Pb 11% $p = .70$	No difference biliary complications (leak, stricture)	No difference Cl-25 (12-129) Pb-23 (12-101)
Ghinolfi,[28] 2011 PCS	No difference PCS, Pb 416 +/- 134 min No PCS, Pb 431 +/- 124, NS	Significantly less pRBCs given in PCS, Pb group pRBC given PCS, Pb 7.5 +/- 5.8 U No PCS, Pb 12.2 +/- 14.2 U $p = .006$	No difference 90-day mortality PCS, Pb 3.4% No PCS, Pb 10%, NS	NA	NA	NA
Grande,[29] 1996 Randomized control trial for VVB in OLT	NA	No difference pRBCs given VVB 5 (0-23) U No VVB 4 (1-16), NS	NA	No difference Serum creatinine level at post-op day 7 VVB .9 (.4-3.3) No VVB 1.0 (.4-4.7), NS	NA	NA
Hesse,[30] 1997 Single center, SS with none, VVB or PCS	No difference SS- 500+/-241 SS, VVB- 365+/-339 SS, PCS- 390+/-284	Higher in SS only than SS,VVB and SS, PCS SS- 16.4+/-15.8 SS, VVB- 4.5 +/-10.5 SS, PCS- 1.2 +/-2.3	NA	No statistical difference (numbers not provided)	NA	NA
Hesse,[31] 2000 Single center experience with Cl, Pb, SS	No difference Cl- 580.2 +/-137.5 PB- 622.9+/-107.6 SS-524.9 +/- 185.8, NS	Cl, Pb significantly higher than SS Cl-20.4 +/- 18.9 Pb- 29.6 +/-25.1 SS- 10.8 +/- 18.6	NA	No difference Cl-2.3 +/-.7 Pb-2.99 +/-1.74 SS-2.12 +/-.2	Increased hepatovenous anastomosis complications in the SS group, (4v.0v.0, $p = .03$) no difference in complications in HAT, PVT, postop ascites, between groups	NA

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Isern,[32] 2004 Randomized control trial for CI, VVB vs Pb, VVB	No difference CI 657.5 (420-925) min Pb 600 (370-960) min, NS	No difference pRBCs given CI 5.5 (0-34) min Pb 5.0 (0-35) min, NS	No difference 30 day mortality CI 0% Pb 3%, NS	NA	NA	No difference CI- 15.5 (6-72) days Pb- 17.0 (10-45) days, $p = .846$
Jovine,[5] 1997 Randomized control trial for CI, VVB vs Pb, VVB	No difference CI 506 +/- 85 min Pb 462 +/- 87 min, NS	No difference pRBCs given CI 2500 +/- 2400 mL Pb 2100 +/- 1200 mL, NS	No difference, numbers not specified	Significantly less incidence of renal failure in Pb group Renal failure incidence CI 30.8% Pb 0% $p < .05$	No difference, numbers not specified	NA
Khan,[33] 2006 SS vs CI, VVB	No difference CI 5.3 (3.5 – 7.3) hrs SS 5.1 (3.6 – 7) hrs, NS	No difference pRBCs given CI 5 (0-9) U SS 4 (0-9) U, NS	No difference 30 day mortality CI 10.8% SS 6.5%, NS	No difference CL 116 (35-135) um SS 112 (32-129) um, NS	No difference between groups for HAT, NS	No difference CI-13 (8-21) SS- 11.5 (7-19), NS
Kim,[34] 2018 Single center divided 300 cases into three groups by order of operation date	Significant difference between groups Group 1 750 (sd 137) min Group 2 722 (sd 141) min Group 3 671 (sd 95) min $p < .001$	Significant difference between groups pRBCs given Group 1 18 (14-28) U Group 2 6 (4-9) U Group 3 4 (2-8) U $p < .001$	NA	NA	NA	NA
Kuo,[35] 1995 VVB vs No VVB in CL	Significantly less operative time in No VVB group VVB 8.5 +/- .5 hr No VVB 5.5 +/- .3 hr $p < .02$	No difference pRBCs given VVB 27.4 +/- 5.6 U No VVB 23.5 +/- 7 U, NS	NA	No difference Peak creatinine (POD 0–14) VVB 2.7 +/- .6 No VVB 2.7 +/- .5, NS	NA	No difference VVB 22.1+/-3.3 days No VVB 18.1 +/-2.1, NS

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Lerut,[36] 1997 Single-center experience with CI, VVB vs. Pb vs. Pb, VVB	NA	CI CI, VVB-8418+/-7728 Pb,-3889.1+/-5688.1 SS- 1522.8 +/-1878.9	No difference 90 day mortality CI, VVB-13.2% Pb, - 2.6% SS-12.8%	NA	NA	NA
Lerut,[37] 2003 Single-center experience with SS, no VVB	475 (185-1080) min	1000 (range 0–14 560) mL	90 day survival 94.7%	NA	NA	15 days (0-206)
Levi,[38] 2012 Comparison of two eras for Pb	Era 2 significantly shorter Era 1 600 min Era 2 548 min $p = .0000$	pRBCs given Era 1 10 U Era 2 9 U, NS	30 day mortality Era 1 4.6% vs. Era 2 3%, $p = .02$	NA	NA	Era 1 21.5+/-.7 days Era 2 15.8+/-.8 days
Mangus,[39] 2007 PGB	NA	3 U PRBC	91.3% 3 month survival	NA	NA	11 (0-250)
Margarit,[40] 1994 CI, VVB vs CI, no VVB vs Pb	Significantly more operative time in CI, VVB group CI, VVB 562 +/- 109 min CI, No VVB 428 +/- 87 min Pb 453 +/- 115 min $p < .01$	Significantly more pRBCs given in CI, VVB group pRBCs given CI, VVB 18 +/- 14 U CI, No VVB 8 +/- 4 U Pb 7.8 +/- 11 U $p < .001$	No difference 1 month survival CI, VVB 21.9% CI, No VVB 12.5% Pb 7.9%, NS	No difference Serum creatinine post-op CI, VVB 2.1 +/- .9 CI, No VVB 1.7 +/- 1 Pb 1.8 +/- 1.1, NS	NA	NA
Margarit,[41] 2005 PCS, Pb vs. No PCS, Pb	No difference PCS, Pb 330 +/- 63 min No PCS, Pb 339 +/- 35 min, NS	NA	NA	NA	NA	NA

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Mehrabi,[42] 2009 SS	320 min	3 U PRBC	90 day mortality- 13.3%	NA	NA	26 days
Miyamoto,[43] 2004 CI vs. Pb	No difference CI 10 (5.5-18) hrs Pb 9.4 (4.8-14.6) hrs, NS	Significantly less pRBCs given in Pb group pRBCs given CI 10 (0-51) U Pb 4 (0-33) U $p < .01$	NA	No difference in change in creatinine	No difference in Complications per patient CI-1.0(1-6) Pb- .8 (1-7)	NA
Moreno- Gonzalez,[44] 2003 Pb vs CI, VVB vs CI, No VVB	Pb longer operative time Pb 121.54 +/- 37.77 min CI, VVB 78.73 +/- 11.89 min CI, No VVB 87.07 +/- 14.33 min $p = .001$	Significantly less pRBCs given in Pb group pRBCs given Pb 12 +/- 7.43 U CI, VVB 17.59 +/- 18.03 U CI, No VVB 23.8 +/- 11.46 U $p = .043$	NA	NA	No difference in % of postoperative complications Pb 18% CI, VVB 18.7% CI, No VVB 6.2% , NS	NA
Mossdorf,[45] 2015 Single center experience with VVB	CI, VVB 269 (171-594) min	pRBCs given CI, VVB 7 (0-56) U	30 day mortality CI, VVB 3%	Creatinine day 3 CI, VVB 2.0	NA	NA
Muscari,[46] 2005 Single center experience with PCS, Pb	PCS, Pb 5hr 30 min (3hr 20 min – 9 hr 30 min)	pRBCs given PCS, Pb 5 (0-30) U	NA	NA	Early complication rate- 7%	NA
Nacif[47] 2020 CI, No VVB vs. Pb, No VVB	Significantly less operative time in PCS, Pb group PCS, Pb 375.64 (sd, 169.3) min No PCS, Pb 442.81 (sd, 130.89) min $p < .001$	No difference pRBCs given PCS, Pb 2.74 (sd 3.49) No PCS, Pb 2.71 (sd 3.36) $p = .66$, NS	NA	Significantly lower serum creatinine level at post-op day 3 in PCS, Pb group Serum creatinine level at day 3 PCS, Pb 1.81 (sd 1.17) No PCS, Pb 2.0 (sd 1.3) $p = .029$	Significantly lower in PCS, Pb group Clavien-Dindo > / = 3 PCS, Pb 58.68% No PCS, Pb 67.52% $p = .006$	Significantly lower in PCS, Pb group PCS, Pb 29.38 (SD 31.56) No PCS, Pb 33.22 (SD 33.44) $p < .001$

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Nishida,[48] 2006 CI vs Pb	Significantly less operative time in Pb group CI 640.6 +/- 183.3 Pb 607.5 +/- 177.8 min $p = .038$	Significantly less blood requirements in Pb group Blood requirements CI 17.6 +/- 17.8 U Pb 13.4 +/- 11.5 U $p = .0002$	NA	No difference Serum creatinine level at post-op day 3 CI 1.48 +/- .91 Pb 1.62 +/- 1.02, NS	No difference (refractory ascites (RA), anastomotic stricture (AS)) CI RA- 5.4% CI AS- .67% Pb RA-8.2% Pb AS-.54%, RA, AS- NS	No difference CI 24.6 +/-29.3 Pb 22.1+/-24.7 days NS $p = .28$
Pratschke,[49] 2012 Is PCS useful?	NA	No difference pRBCs given PCS, Pb 5.0 +/- 4.0 U PCS Pb 4.4 +/- 5.0 U, NS $p = .8$	NA	No difference Serum creatinine at post-op day 7 $p > .05$	NA	NA
Rayar,[50] 2017 PCS in OLT propensity score analysis	Significantly less operative time in No PCS, SS group PCS, SS 388 (175 – 655) min No PCS, SS 362 (160 – 665) min $p = .03$	Significantly less pRBCs given in PCS, SS group pRBCs given PCS, SS 5 (0-36) U No PCS, SS 6 (0- 40) U $p = .02$	No difference 3 month survival PCS, SS 93.1% No PCS, SS 95%, $p = .74$	NA	No difference Clavien-Dindo > / = 3 PCS, SS 24.2% No PCS, SS 28.3%, $p = .41$	No difference PCS, SS 20 [1-232] No PCS, SS 20 [1-102], $p = .49$
Reddy,[51] 2000 Pb vs. CI, Pb with selective use of VVB	Significantly less operative time in Pb group CI 9.5 +/- 3.2 hr Pb 7.6 +/- 1.6 hr $p = .002$	Significantly less pRBCs given in Pb group pRBCs given CI 15 +/- 12 U Pb 9 +/- 8 U $p = .023$	NA	No difference Serum creatinine post-op day 3 CI 1.6 +/- .9 Pb 1.7 +/- .9, NS	NA	No difference CI-17 days Pb- 11 days, NS

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Remiszewski,[52] 2006 Pb vs. CI	NA	NA	NA	NA	No difference CI-36% Pb-30%, NS	No difference CI-17 days (10-66) Pb-16 days (11-82), NS
Sakai,[53] 2010 CI, VVB vs. Pb, VVB vs. Pb, No VVB	Significantly less operative time in both Pb groups vs CI CI, VVB 8.9 +/- 2.2 hr Pb, VVB 7.5 +/- 1.8 hr Pb, No VVB 7.6 +/- 1.8 hr	Significantly less pRBCs given in Pb, No VVB group vs other groups pRBCs given CI, VVB 10 (0-86) U Pb, VVB 10 (0-93) U Pb, No VVB 8 (0-45) U	No difference ($p = .051$) 30 day mortality CI, VVB 8.7% Pb, VVB 6.8% Pb, No VVB 2.3%	Significantly less incidence of acute renal failure in Pb, No VVB group vs other groups Acute renal failure (increase of post-op creatinine > = of x3 preop) CI, VVB 34.7% Pb, VVB 24.8% Pb, No VVB 15.4%	No difference in rates of HAT CI, VVB 2.0% Pb, VVB 3.4% Pb, No VVB 0%	No difference CI, VVB 15 (7-185) days Pb, VVB 15 (7-126) Pb, No VVB 13 (7-98)
Schmitz,[54] 2014 CI, VVB vs. CI, No VVB vs. SS	NA	Significantly less pRBCs given in SS group compared to CI groups pRBCs given SS 6.1 +/- 6 U CI, VVB 9.8 +/-12.5 CI, No VVB 7.8 +/- 9.5 $p = .002$	NA	No difference Day 7 creatinine SS 1.37 +/- .85 CI, VVB 1.57 +/- 1.17 CI, No VVB 1.57 +/- .98 $p = .232$, NS	SS with more biliary leaks, HA stenosis and HV stenosis than CI No difference in Infectious complications or biliary stenosis, PV thrombosis HA SS 4.0 CI, VVB 1.6 CI, No VVB .9 $p = .0045$ HV SS 1.7 CI, VVB .8 CI, No VVB 0 $p = .018$ Biliary leaks SS 9.1 CI, VVB 2.4 CI, No VVB 4.5 $p = .042$	NA

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Shokouh-Amiri,[55] 2000 Single center experience with CI, VVB vs Pb	Pb shorter op time Pb- 425+/-16 CI, VVB- 486 +/-12, $p < .003$	No difference Pb- 8.9+/-7.4 CI, VVB- 12.1+/-12.4, $p = .18$	NA	NA	NA	Shorter length of stay for Pb group Pb-11.6+/-1.1 days CI, VVB- 14.4+/-.8, $p < .05$
Suarez-Munoz,[56] 2006 PCS	Significantly less operative time in PCS, Pb group PCS, Pb 361 min No PCS, Pb 435 min $p < .001$	Significantly less recovered RBCs in PCS, Pb group Recovered RBCs PCS, Pb 969cc No PCS, Pb 2999cc $p < .001$	NA	No difference Maximum immediate post-op creatinine PCS, Pb 1.67 No PCS, Pb 1.87, NS	NA	Shorter LOS for PCS,PB PCS, Pb 12.7 No PCS, Pb 18.9, $p = .001$
Sun,[57] 2017 CI, VVB vs. CI, no VVB	Significantly less operative time in CI, No VVB group CI, VVB 389 (342-426) CI, No VVB 288 (256-332) min $p < .001$	Significantly less pRBCs given in CI, No VVB group pRBCS given CI, VVB 19 (11-30) U CI, No VVB 13 (8-18) U $p < .001$	NA	No difference Acute kidney injury incidence CI, VVB 51.1% CI, No VVB 55.2%, NS	NA	NA
Vieira de Melo,[58] 2011 CI, No VVB vs. Pb, No VVB	Significantly less operative time in Pb group CI 489 +/- 129 min Pb 437 +/- 113 min $p < .01$	Significantly less pRBCs given in Pb group pRBCs given CI 4.3 +/- 3.9 U Pb 3 +/- 2.6 U $p < .01$	Significantly less 30 day mortality for Pb group CI 12% Pb 2.85%, $p = .03$	No difference Urine output at day 1 CI 3529 +/- 1558 mL Pb 3092 +/- 1494 mL, NS	NO difference between groups in biliary, HA, PV complication rate	No difference in LOS > 15 days CI-28.8% Pb-22.8%, NS

(Continues)

TABLE 2 (Continued)

	Operation duration	Blood transfusion	30 or 90-day mortality / survival	Renal Function	Complications	Hospital LOS
Widmer,[59] 2018 CI vs. Pb	Significantly less operative time in CI group CI 6.2 (5.2 – 7.3) hr Pb 6.7 (5.8-7.8) hr $p = .01$	Significantly less pRBCs given in Pb group pRBCs given CI 3 (0-7) U Pb 2 (0-4) U $p = .02$	NA	No difference Acute kidney injury incidence CI 14.9% Pb 14.7%, NS	No difference In 3 month CCI (Comprehensive Complication Index) CI 34.6 (26.2-47.3) Pb 33.5 (21.8-47.4), $p = .9$	Shorter hospital stay for Pb group CI 18 (15-27) Pb 17 (13-23), $p = .05$
Wu,[60] 2001 Single-center experience with SS	SS 4hr 30 min (2 hr 6 min- 9 hr 20 min)	pRBCs given SS 6 (0-49) U	NA	No difference Maximum creatinine in first 5 days post op SS 1.9 +/- 1.2 SS, VVB creatinine increase of .1 SS, No VVB creatinine increase of .2, NS	Outflow obstruction-0 Hepatic artery thrombosis within 1 year -.9% Bile duct stricture 7% Bile leak 1.7%	10 days (2-144)

CI- Classic caval resection, VVB-venovenous bypass, SS-side to side cavocavostomy, LOS-length of stay, PCS-portocaval shunt, POD-postoperative day, ICU-intensive care unit, Pb-Piggyback technique, pRBCs-packed red blood cells, AKI-acute kidney injury, OLT-orthotopic Liver transplant, NS-not significant, NA-not applicable.

TABLE 3

A. Piggyback vs. caval replacement									
Summary of Findings									
Number of studies									
RCT	**Observational comparative**	**Observational non-comparative**	**Effect from comparative studies**	**Limitations**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication Bias**	**Quality of Evidence (GRADE)**
Outcome 1: ***Operation duration***									
2	16	21	Shorter operative time in Pb group	Serious	Very Serious	Not serious	Not serious	Not likely	Low ●●○○
Outcome 2: ***Blood Loss***									
2	18	23	Less pRBCs transfused in the Pb group	Serious	Very Serious	Very serious	Not Serious	Not likely	Low ●●○○
Outcome 3: ***Mortality***									
2	9	9	no difference between Pb and Cl groups in most studies	Serious	Not serious	Not serious	Serious	Not likely	Low ●●○○
Outcome 4: ***Renal Function***									
1	14	13	no difference between Pb and Cl groups in most studies	Serious	Serious	Serious	Serious	Not likely	Low ●●○○
Outcome 5: ***Complications***									
1	14	6	no difference between Pb and Cl groups in most studies	Very serious	Serious	Very serious	Serious	Not likely	Low ●●○○
Outcome 6: ***Hospital LOS***									
1	13	11	no difference between Pb and Cl groups in most studies	Serious	Not serious	Not serious	Serious	Not likely	Low ●●○○

(Continues)

TABLE 3 (Continued)

B. Temporary portocaval shunt vs. no temporary portal caval shunt									
Summary of Findings									
Number of studies									
RCT	**Observational comparative**	**Observational non-comparative**	**Effect from comparative studies**	**Limitations**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication Bias**	**Quality of Evidence (GRADE)**
Outcome 1: ***Operative Time***									
1	5	3	No difference between PCS and No PCS groups	Serious	Not serious	Not serious	Serious	Likely	Low ●●○○
Outcome 2: ***Blood Loss***									
1	6	3	Lower pRBCs transfused in PCS group	Serious	Serious	Very serious	Serious	Likely	Low ●●○○
Outcome 3: ***Mortality***									
0	2	2	No difference between PCS and No PCS groups	Serious	Not serious	Not serious	Very serious	Likely	Very low ●○○○
Outcome 4: ***Renal Function***									
1	4	2	No difference between PCS and No PCS groups	Serious	Not serious	Serious	Very serious	Likely	Low ●●○○
Outcome 5: ***Complications***									
0	2	2	No difference between PCS and No PCS groups	Serious	Not serious	Very serious	Very serious	Likely	Very low ●○○○
Outcome 6: ***Hospital LOS***									
0	2	2	Shorter LOS in PCS group	Serious	Serious	Not serious	Very serious	Likely	Very low ●○○○

(Continues)

TABLE 3 (Continued)

C. Venovenous bypass vs no venvenous bypass									
Summary of Findings									
Number of studies									
RCT	**Observational comparative**	**Observational non-comparative**	**Effect from comparative studies**	**Limitations**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication Bias**	**Quality of Evidence (GRADE)**
Outcome 1: *Operative Time*									
0	7	9	Shorter operative duration in no VVB group	Serious	Serious	Not serious	Serious	Not likely	Very low ●○○○
Outcome 2: *Blood Loss*									
1	9	9	Less pRBCs transfused in no VVB group	Serious	Serious	Serious	Serious	Not likely	Low ●●○○
Outcome 3: *Mortality*									
0	3	7	no difference between VVB and no VVB group	Serious	Not serious	Serious	Very serious	Not likely	Very low ●○○○
Outcome 4: *Renal Function*									
1	9	5	no difference between VVB and no VVB group	Serious	Not serious	Serious	Serious	Not likely	Low ●●○○
Outcome 5: *Complications*									
0	3	3	no difference between VVB and no VVB group	Serious	Not serious	Very serious	Very serious	Likely	Very low ●○○○
Outcome 6: *Hospital LOS*									
0	3	6	no difference between VVB and no VVB group	Serious	Not serious	Not serious	Very serious	Not Likely	Very low ●○○○

Pb-Piggyback, Cl-Classic caval resection, pRBC-packed red blood cells, PCS-Porto-caval shunt, VVB-veno-venous bypass, LOS-length of stay.
For Table 3A-Low quality of evidence despite RCTs secondary to dated trials, underpowered for outcomes of interest.
Table 3B,3C-Low quality of evidence despite RCTs secondary to dated trials, underpowered for outcomes of interest, very low quality of evidence for mortality, complications, hospital LOS due to only observational comparative studies with low numbers.

3.23 | Recommendations

The direction and strength of recommendation was rated as strong for the surgical approach based on surgical and institutional preference. The direction and strength of recommendation was rated as strong against the routine use of VVB. The direction and strength of recommendation was rated as strong against the routine use of temporary PCS. (Tables 4A,B,C).

4 | DISCUSSION

4.1 | Cava replacement techniques

With the advent of different cava reconstruction techniques for liver transplantation (LT), there has been a debate as to whether one technique provides advantages over the other with regards to patient outcomes. The panel considered the key clinical outcome variables and there was consensus that immediate/early postoperative outcomes of hospital LOS, operation duration, units of packed red blood cells transfused, early mortality, early complication rates, and renal dysfunction as the outcomes of interest. After reviewing the literature and performing a quality of evidence assessment according to the GRADE criteria, there is a lack of high or moderate quality evidence for each of outcomes. The two RCTs that were included were limited and underpowered for the immediate and short-term outcomes we were interested in. The only differences that were apparent were that the Piggyback (Pb) group is related to a shorter operation duration and fewer PRBCs transfused. The expert panel's recommendation was made that the surgical approach based on surgeon and institutional preferences, with special consideration toward certain patient-related factors. The panel cannot recommend one technique over the another with regard to the outcomes considered. There is a need for multicenter, prospective randomized trials to delineate the immediate and short-term outcomes between the different surgical approaches.

There have been many modifications to the caval-preserving methods used in different conditions and indications at the time of transplantation. The essential part of all these methods is to preserve the inferior vena cava. We did not analyze the many variants of the PB technique to determine whether any methods are better than others. These technical variants require careful evaluation and comparison to determine the relative benefits and harms of each of the different techniques. The primary end points of such studies should be identified in advance to ensure they can adequately determine the optimal technique.

The degree of caval occlusion during piggyback technique can be variable depending on caval anatomy and positioning of clamp. Oliver et al. measured the anhepatic inferior vena cava pressure gradient and found that it varied substantially, with pressure gradient being linearly associated with early acute kidney injury (AKI).[61] This suggests that renal venous congestion is an etiological factor to post operative AKI. Fabes et al. described a less invasive method of assessing the gradient using saphenous vein pressure monitoring.[62]

4.2 | Venovenous bypass

With regard to the routine use of VVB, similar to the cava reconstruction technique, the panel considered the key clinical outcome variables and there was consensus that the immediate/early postoperative outcomes of hospital LOS, operation duration, units of packed red blood cells transfused, early mortality, early complication rates, and renal dysfunction as the outcomes of interest. After reviewing the literature and performing a quality of evidence assessment according to the GRADE criteria, the quality evidence for each of the outcomes was very low. The one RCT that was included was limited and underpowered for the immediate and short-term outcomes we were interested in. The only differences that were found were that the group with VVB had longer operative duration and more PRBCs transfused. The expert panel's recommendation was against routine use of VVB in liver transplantation, while recognizing that there are certain situations where it can be considered, but in such situations, there needs to a balance that includes surgeon familiarity, organizational familiarity, and level of experience of the anesthesiology team. There is a need for multicenter, prospective randomized trials to delineate the immediate and short-term outcomes for the routine use of VVB.

Advantages of VVB include a reduction in cardiovascular instability resulting from reduced venous return to the heart during venous cross-clamping, particularly in patients with acute liver failure or in patients with noncirrhotic indications for OLT who may not have developed portosystemic venous collaterals.[7] Since our review did not find an impact on mortality, complication rate, renal function, or hospital stay, then the importance of achieving this reduction in cardiovascular instability is not clear.

However, the VVB can cause complications, some of them fatal. Complications associated with VVB were described as occurring in 10–30% of cases.[63] These include seroma at the site of cannulae insertion, hematoma, wound infection, deep venous thrombosis, and nerve injury.[7,64,65] The most frequent complications are wound lymphocoeles, both in the inguinal and axillary incisions. They can be avoided by careful dissection and ligation of all lymphatics. Lymphocoeles are usually self-limiting and self-healing, but occasionally chronic lymphorrhea can be quite disabling and requires surgical correction.[64,65] Less invasive approaches to percutaneous cannulation of the femoral vein and internal jugular vein may obviate wound complications associated with cutdowns, however the risk of hematoma formation or venous perforation exists with these techniques.[66] Mortality has also been described with an air embolus at the time of decannulation as well as intracircuit clots and a subsequent pulmonary embolus, the latter having occurred mainly when non-heparin bonded tubing was used.[65]

4.3 | Temporary portocaval shunt

With regard to the routine use of temporary PCSs, the panel considered the key clinical outcome variables and there was consensus that the immediate and early postoperative outcomes of hospital LOS, operative duration, units of packed red blood cells transfused, early

TABLE 4

A. Cava anastomotic techniques			
Question: Which cava anastomotic techniques are optimal regarding immediate and short-term outcomes after liver transplantation?			
	Judgment		
Decision domain	**Yes**	**No**	**Reason for Judgment**
Balance between desirable and undesirable outcomes (estimated effects), with consideration of values and preferences (estimated typical)		✓	There was no difference in immediate and short term outcomes after liver transplantation between the different cava anastomotic techniques with regard to hospital stay, postoperative renal dysfunction, complication rates, and early mortality. With regard to the operative duration and units pRBCs transfused, the Pb group had lower operative duration and less pRBCs transfused.
Confidence in the magnitude of estimates of effect of the interventions on important outcomes (overall quality of evidence for outcomes)		✓	pRBCs transfused, early mortality, postoperative renal function, complication rate: Very low ●○○○ Hospital LOS and Operative duration: Low ●●○○
Confidence in Values and Preference, and their Variability		✓	Based on the limited data and clinical experience of all the authors, it is difficult to recommend one cava anastomotic technique over the other.
Resource implications	✓		If Caval replacement is used with VVB, then there are more resources required to put a patient on venovenous bypass. This includes additional costs and personnel. If no VVB is used, the resource implications are negligible.
Overall Quality of Evidence: ***Low***			
Recommendation: Strong for			Surgical approach based on surgeon preference and center dependent, with special consideration towards certain, panel cannot recommend one technique vs another with regard to main outcomes
B. Temporary Portocaval Shunt			
Question: Temporary Portocaval Shunt			
	Judgment		
Decision domain	**Yes**	**No**	**Reason for Judgment**
Balance between desirable and undesirable outcomes (estimated effects), with consideration of values and preferences (estimated typical)	✓		There was no difference in immediate and short term outcomes after liver transplantation between the different cava anastomotic techniques with regard to postoperative renal dysfunction, complication rates, operative duration and early mortality. With regard to the units of pRBCs transfused, the no PCS group had fewer units transfused. With regard to hospital LOS, the PCS group had lower LOS.
Confidence in the magnitude of estimates of effect of the interventions on important outcomes (overall quality of evidence for outcomes)		✓	Early mortality, Hospital LOS, complication rate: Very low ●○○○ RBCs transfused, renal function, Operative duration: Low ●●○○
Confidence in Values and Preference, and their Variability		✓	Based on the limited data and clinical experience of all the authors, there is limited application of temporary portocaval shunts in vena cava-preserving liver transplantation and no role for routine use of PCS.
Resource implications		✓	In the case of temporary portocaval shunt placement, the resources required for its placement are negligible.
Overall Quality of Evidence: ***very low***			
Recommendation: Strong			Considering all decision domains, the guideline panel recommends against routine use of temporary PCS

(Continues)

TABLE 4 (Continued)

C. Veno-venous bypass			
Question: Veno-venous bypass			
	Judgment		
Decision domain	**Yes**	**No**	**Reason for Judgment**
Balance between desirable and undesirable outcomes (estimated effects), with consideration of values and preferences (estimated typical)		✓	There was no difference in immediate and short term outcomes after liver transplantation between the different cava anastomotic techniques with regard to hospital stay, postoperative renal dysfunction, complication rates, and early mortality. With regards to operative duration, units pRBCs transfused, the venovenous bypass group had shorter operative duration and fewer units of PRBCs transfused.
Confidence in the magnitude of estimates of effect of the interventions on important outcomes (overall quality of evidence for outcomes)		✓	Early mortality, complication rate, Hospital LOS and Operative duration: Very low ●○○○ pRBCs transfused, postoperative renal function: Low ●●○○
Confidence in Values and Preference, and their Variability	✓		Based on the limited data and clinical experience of all the authors, there is limited application of venovenous bypass in liver transplantation and no role for routine use of VVB.
Resource implications	✓		It is well known that more resources are required to put a patient on venovenous bypass. This includes additional costs and personnel. By not routinely using venovenous bypass, significant resources are saved by not using VVB.
Overall Quality of Evidence: *very low*			
Recommendation: Strong			Against routine use of venovenous bypass in Liver transplantation. There are certain situations where it can be considered, but in such situations there needs to balance that includes surgeon familiarity, organizational familiarity and level of experience of the anesthesiology team

Pb-Piggyback, CI-Classic caval resection, pRBC-packed red blood cells, PCS-Porto-caval shunt, VVB-veno-venous bypass, LOS-length of stay.

mortality, early complication rates, and renal dysfunction as the outcomes of interest. After reviewing the literature and performing a quality of evidence assessment according to the grade criteria, the quality evidence for each of the outcomes was very low. The one RCT that was included was limited and underpowered for the immediate and short-term outcomes we were interested in. The only differences that were found were that the PCS group had fewer PRBCs transfused and shorter hospital LOS. Considering all decision domains, the expert panel's recommendation was against routine use of temporary PCS placement in liver transplantation, recognizing that there are rare cases where a temporary PCS might be beneficial. There is a need for multicenter, prospective randomized trials to delineate the immediate and short-term outcomes for the routine use of PCS.

4.4 | Limitations

The limitations of this study are that the quality of evidence was low to very low. The great majority of comparative studies were single center and retrospective, with no recent, prospective RCTs.

5 | CONCLUSION

The panel cannot recommend one cava reconstruction technique over another, but rather the surgical approach should be based on surgeon preference and center dependent, with special consideration toward patient circumstances (Quality of evidence: Low | Grade of Recommendation: Strong). The panel recommends against routine use of VVB (Quality of evidence: Very Low | Grade of Recommendation: Strong) and against the routine use of temporary porto-caval shunt (Quality of evidence: Very Low | Grade of Recommendation: Strong). There is a need for multicenter, prospective randomized trials to evaluate the benefits and harms of the different cava reconstruction techniques, the routine use of VVB, and the routine use of temporary PCS.

ACKNOWLEDGMENTS

This manuscript was prepared for the ERAS4OLT.org Consensus Conference 2022, which is partially funded by the International Liver Transplant Society (ILTS).

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Data collection/analysis/interpretation, drafting article, critical revision of article, approval of article were performed by TMS, JDE, BRD, RNB, JP, OI, JF. MS and DAR have conceived and designed the project, the systematic review strategies, prepared the PROSPERO protocols, supervised screening the records, and assessing the full-text articles for eligibility, prepared the structure of the statement manuscript template, revised the manuscript, and approved the article.

All authors qualify for authorship as per the International Committee of Medical Journal Editors (ICMJE) guidelines.

ERAS4OLT.org WORKING GROUP AUTHORSHIP

Claus Niemann, San Francisco, CA, USA, Joerg-Matthias Pollok, London, UK, Marina Berenguer, Valencia, Spain, Pascale Tinguely, London, UK. Manikandan Kathirvel, London, UK, Nolitha Morare, London, UK.

DATA AVAILABILITY STATEMENT

Data sharing not applicable – no new data generated.

REFERENCES

1. Starzl TE, Marchioro TL, Von Kaula KN, et al. Homotransplantation of the liver in humans. *Surg Gynecol Obstet*. 1963;117:659-667.
2. Tzakis A, Todo S, Starzl TE. Orthotopic liver transplantation with preservation of inferior vena cava. *Ann Surg*. 1989;210:649-652.
3. Belghiti J, Panis Y, Sauvanet A, Gayet B, Fékété F. A new technique of side to side caval anastomosis during orthotopic hepatic transplantation without inferior vena caval occlusion. *Surg Gynecol Obstet*. 1992;175(3):270-272.
4. Bismuth H, Castaing D, Sherlock DJ. Liver transplantation by "face-à-face" venacavaplasty. *Surgery*. 1992;111(2):151-155.
5. Jovine E, Mazziotti A, Grazi GL, et al. Piggy-back versus conventional technique in liver transplantation: report of a randomized trial. *Transpl Int*. 1997;10(2):109-112. https://doi.org/10.1007/pl00003824
6. Shaw BW Jr, Martin DJ, Marquez JM, et al. Venous bypass in clinical liver transplantation. *Ann Surg*. 1984;200(4):524-534. https://doi.org/10.1097/00000658-198410000-00013
7. Tzakis A, Reyes J, Nour B, Marino I, Todo S, Starzl T. Temporary end to side portacaval shunt in orthotopic he-patic transplantation in humans. *Surg Gynecol Obstet*. 1993;176:180-182.
8. Gurusamy KS, Pamecha V, Davidson BR. Piggy-back graft for liver transplantation. *Cochrane Database Syst Rev*. 2011;1:CD008258. https://doi.org/10.1002/14651858.CD008258.pub2 Published 2011 Jan 19
9. Gurusamy KS, Koti R, Pamecha V, Davidson BR. Veno-venous bypass versus none for liver transplantation. *Cochrane Database Syst Rev*. 2011;3:CD007712. https://doi.org/10.1002/14651858.CD007712.pub2 Published 2011 Mar 16
10. Kluger MD, Memeo R, Laurent A, et al. Survey of adult liver transplantation techniques (SALT): an international study of current practices in deceased donor liver transplantation. *HPB*. 2011;13(10):692-698. https://doi.org/10.1111/j.1477-2574.2011.00348.x
11. Guyatt G, Oxman AD, Akl EA, et al. GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol*. 2011;64:383. https://linkinghub.elsevier.com/retrieve/pii/S0895435610003306
12. Murad MH, Mustafa RA, Schünemann HJ, Sultan S, Santesso N. Rating the certainty in evidence in the absence of a single estimate of effect. *Evid Based Med*. 2017;22:85. https://ebm.bmj.com/lookup/doi/10.1136/ebmed-2017-110668
13. Andrews J, Guyatt G, Oxman AD, et al. GRADE guidelines: 14. Going from evidence to recommendations: the significance and presentation of recommendations. *J Clin Epidemiol*. 2013;66:719. https://linkinghub.elsevier.com/retrieve/pii/S0895435612001382
14. Andrews JC, Schünemann HJ, Oxman AD, et al. GRADE guidelines: 15. Going from evidence to recommendation—determinants of a recommendation's direction and strength. *J Clin Epidemiol*. 2013;66:726. https://linkinghub.elsevier.com/retrieve/pii/S0895435613000541
15. Arzu GD, De Ruvo N, Montalti R, et al. Temporary Porto-Caval shunt utility during orthotopic liver transplantation. *Transplant Proc*. 2008;40(6):1937-1940. https://doi.org/10.1016/j.transproceed.2008.06.001
16. Audet M, Piardi T, Panaro F, et al. Four hundred and twenty-three consecutive adults piggy-back liver transplantations with the three suprahepatic veins: was the portal systemic shunt required?: adults piggyback liver transplantation. *J Gastroenterol Hepatol*. 2010;25(3):591-596. https://doi.org/10.1111/j.1440-1746.2009.06084.x
17. Barbas AS, Levy J, Mulvihill MS, et al. Liver transplantation without venovenous bypass: does surgical approach matter? *Transplant Direct*. 2018;4(5):e348. https://doi.org/10.1097/TXD.0000000000000776
18. Barshes NR, Lee T, Kiliç M, Goss JA. Reconstruction of the hepatic venous outflow in piggyback liver transplantation. *Exp Clin Transplant*. 2004;2(1):189-195.
19. Brescia MDG, Massarollo PCB, Imakuma ES, Mies S. Prospective randomized trial comparing hepatic venous outflow and renal function after conventional versus piggyback liver transplantation. Herrero JI, ed. *PLoS One*. 2015;10(6):e0129923. https://doi.org/10.1371/journal.pone.0129923
20. Busque S, Esquivel CO, Concepcion W, So SK. Experience with the piggyback technique without caval occlusion in adult orthotopic liver transplantation. *Transplantation*. 1998;65(1):77-82. https://doi.org/10.1097/00007890-199801150-00015
21. Cabezuelo JB, Ramirez P, Acosta F, et al. Does the standard vs piggyback surgical technique affect the development of early acute renal failure after orthotopic liver transplantation? *Transplant Proc*. 2003;35(5):1913-1914. https://doi.org/10.1016/S0041-1345(03)00598-0
22. Carvalho EM, Massarollo PCB, Isern MRM, et al. Pulmonary evolution in conventional liver transplantation with venovenous bypass and the piggyback method. *Transplant Proc*. 1999;31(7):3064-3066. https://doi.org/10.1016/S0041-1345(99)00674-0
23. Chan T, DeGirolamo K, Chartier-Plante S, Buczkowski AK. Comparison of three caval reconstruction techniques in orthotopic liver transplantation: a retrospective review. *Am J Surg*. 2017;213(5):943-949. https://doi.org/10.1016/j.amjsurg.2017.03.045
24. de Cenarruzabeitia IL, Lázaro JL, Bilbao I, Balsells J. Portocaval shunt throughout anhepatic phase in orthotopic liver transplantation for cirrhotic patients. *Transplant Proc*. 2007;39(7):2280-2284. https://doi.org/10.1016/j.transproceed.2007.07.045
25. Figueras J. Temporary portocaval shunt during liver transplantation with vena cava preservation. results of a prospective randomized study. *Liver Transpl*. 2001;7(10):904-911. https://doi.org/10.1053/jlts.2001.27870
26. Fleitas MG. Could the piggyback operation in liver transplantation be routinely used? *Arch Surg*. 1994;129(8):842. https://doi.org/10.1001/archsurg.1994.01420320068013
27. Ghazaly M, Davidson BR. Conventional versus piggyback techniques: do they have different outcomes? *Prog Transpl*. 2014;24(1):51-55. https://doi.org/10.7182/pit2014566
28. Ghinolfi D, Martí J, Rodríguez-Laiz G, et al. The beneficial impact of temporary porto-caval shunt in orthotopic liver transplantation: a

single center analysis: the temporary porto-caval shunt in liver transplantation. *Transpl Int*. 2011;24(3):243-250. https://doi.org/10.1111/j.1432-2277.2010.01168.x

29. Grande L, Rimola A, Cugat E, et al. Effect of venovenous bypass on perioperative renal function in liver transplantation: results of a randomized, controlled trial: effect of venovenous bypass on perioperative renal function in liver transplantation: results of a randomized, controlled trial. *Hepatology*. 1996;23(6):1418-1428. https://doi.org/10.1002/hep.510230618
30. Hesse UJ, Berrevoet F, Troisi R, Mortier E, Pattyn P, de Hemptinne B. Liver transplantation by preservation of the caval flow with temporary porto-caval shunt or veno-venous bypass. *Transplant Proc*. 1997;29(8):3609-3610. https://doi.org/10.1016/S0041-1345(97)01044-0
31. Hesse UJ, Berrevoet F, Troisi R, et al. Hepato-venous reconstruction in orthotopic liver transplantation with preservation of the recipients' inferior vena cava and veno-venous bypass. *Langenbeck's Arch Surg*. 2000;385(5):350-356. https://doi.org/10.1007/s004230000149
32. Isern MRM, Massarollo PCB, de Carvalho EM, et al. Randomized trial comparing pulmonary alterations after conventional with venovenous bypass versus piggyback liver transplantation: pulmonary alterations in liver transplantation. *Liver Transpl*. 2004;10(3):425-433. https://doi.org/10.1002/lt.20067
33. Khan S, Silva MA, Tan YM, et al. Conventional versus piggyback technique of caval implantation; without extra-corporeal veno-venous bypass. A comparative study. *Transplant Int*. 2006;19(10):795-801. https://doi.org/10.1111/j.1432-2277.2006.00331.x
34. Kim HY, Ko JS, Joh J, Lee S, Kim GS. Weaning of veno-venous bypass in liver transplantation: a single center experience. *Transplant Proc*. 2018;50(9):2657-2660. https://doi.org/10.1016/j.transproceed.2018.03.075
35. Kuo PC, Alfrey EJ, Garcia G, Haddow G, Dafoe DC. Orthotopic liver transplantation with selective use of venovenous bypass. *Am J Surg*. 1995;170(6):671-675. https://doi.org/10.1016/S0002-9610(99)80039-7
36. Lerut JP, Molle G, Ciccarelli O, et al. Cavocaval liver transplantation without venovenous bypass and without temporary portocaval shunting: the ideal technique for adult liver grafting? *Transplant Int*. 1997;10(3):171-179. https://doi.org/10.1111/j.1432-2277.1997.tb00681.x
37. Lerut J, Ciccarelli O, Roggen F, et al. Cavocaval adult liver transplantation and retransplantation without venovenous bypass and without portocaval shunting: a prospective feasibility study in adult liver transplantation. *Transplantation*. 2003;75(10):1740-1745. https://doi.org/10.1097/01.TP.0000061613.66081.09
38. Levi DM, Pararas N, Tzakis AG, et al. Liver transplantation with preservation of the inferior vena cava: lessons learned through 2,000 cases. *J Am Coll Surg*. 2012;214(4):691-698. https://doi.org/10.1016/j.jamcollsurg.2011.12.039
39. Mangus RS, Kinsella SB, Nobari MM, et al. Predictors of blood product use in orthotopic liver transplantation using the piggyback hepatectomy technique. *Transplant Proc*. 2007;39(10):3207-3213. https://doi.org/10.1016/j.transproceed.2007.09.029
40. Margarit C, Lázaro JL, Balsells J, et al. Recipient hepatectomy with preservation of inferior vena cava reduces the need for veno-venous bypass in liver transplantation. *Transplant Int*. 1994;7(s1):152-154. https://doi.org/10.1111/j.1432-2277.1994.tb01335.x
41. Margarit C, Lopez de Cenarruzabeitia I, Lázaro JL, et al. Portacaval shunt and inferior vena cava preservation in orthotopic liver transplantation. *Transplant Proc*. 2005;37(9):3896-3898. https://doi.org/10.1016/j.transproceed.2005.10.062
42. Mehrabi A, Mood ZA, Fonouni H, et al. A single-center experience of 500 liver transplants using the modified piggyback technique by Belghiti: modified piggyback liver transplantation. *Liver Transpl*. 2009;15(5):466-474. https://doi.org/10.1002/lt.21705
43. Miyamoto S, Polak WG, Geuken E, et al. Liver transplantation with preservation of the inferior vena cava. A comparison of conventional and piggyback techniques in adults. *Clin Transplant*. 2004;18(6):686-693. https://doi.org/10.1111/j.1399-0012.2004.00278.x
44. Moreno-Gonzalez E, Meneu-Diaz JG, Fundora Y, et al. Advantages of the piggy back technique on intraoperative transfusion, fluid compsumption, and vasoactive drugs requirements in liver transplantation: a comparative study. *Transplant Proc*. 2003;35(5):1918-1919. https://doi.org/10.1016/S0041-1345(03)00600-6
45. Mossdorf A, Ulmer F, Junge K, et al. Bypass during liver transplantation: anachronism or revival? Liver transplantation using a combined venovenous/portal venous bypass—experiences with 163 liver transplants in a newly established liver transplantation program. *Gastroenterol Res Pract*. 2015;2015:1-7. https://doi.org/10.1155/2015/967951
46. Muscari F, Suc B, Aguirre J, et al. Orthotopic liver transplantation with vena cava preservation in cirrhotic patients: is systematic temporary portacaval anastomosis a justified procedure? *Transplant Proc*. 2005;37(5):2159-2162. https://doi.org/10.1016/j.transproceed.2005.03.005
47. Nacif LS, Zanini LY, Costa dos Santos JP, et al. Intraoperative temporary portocaval shunt in liver transplant. *Transplant Proc*. 2020;52(5):1314-1317. https://doi.org/10.1016/j.transproceed.2020.02.074
48. Nishida S, Nakamura N, Vaidya A, et al. Piggyback technique in adult orthotopic liver transplantation: an analysis of 1067 liver transplants at a single center. *HPB*. 2006;8(3):182-188. https://doi.org/10.1080/13651820500542135
49. Pratschke S, Meimarakis G, Bruns CJ, et al. Temporary intraoperative porto-caval shunt: useless or beneficial in piggy back liver transplantation? *Transpl Int*. 2013;26(1):90-98. https://doi.org/10.1111/tri.12007
50. Rayar M, Levi Sandri GB, Cusumano C, et al. Benefits of temporary portocaval shunt during orthotopic liver transplantation with vena cava preservation: a propensity score analysis. *Liver Transpl*. 2017;23(2):174-183. https://doi.org/10.1002/lt.24650
51. Reddy KS, Johnston TD, Putnam LA, Isley M, Ranjan D. Piggyback technique and selective use of veno-venous bypass in adult orthotopic liver transplantation: piggyback technique and liver transplantation. *Clin Transplant*. 2000;14(4):370-374. https://doi.org/10.1034/j.1399-0012.2000.14040202.x
52. Remiszewski P, Zieniewicz K, Krawczyk M. Early results of orthotopic liver transplantations using the technique of inferior vena cava anastomosis. *Transplant Proc*. 2006;38(1):237-239. https://doi.org/10.1016/j.transproceed.2005.12.021
53. Sakai T, Matsusaki T, Marsh JW, Hilmi IA, Planinsic RM. Comparison of surgical methods in liver transplantation: retrohepatic caval resection with venovenous bypass (VVB) versus piggyback (PB) with VVB versus PB without VVB: impact of piggyback without venovenous bypass on liver transplant outcomes. *Transpl Int*. 2010;23(12):1247-1258. https://doi.org/10.1111/j.1432-2277.2010.01144.x
54. Schmitz V, Schoening W, Jelkmann I, et al. Different cava reconstruction techniques in liver transplantation: piggyback versus cava resection. *Hepatobiliary Pancreat Dis Int*. 2014;13(3):242-249. https://doi.org/10.1016/S1499-3872(14)60250-2
55. Shokouh-Amiri MH, Osama Gaber A, Bagous WA, et al. Choice of surgical technique influences perioperative outcomes in liver transplantation. *Ann Surg*. 2000;231(6):814-823. https://doi.org/10.1097/00000658-200006000-00005
56. Suárez-Munoz MA, Santoyo J, Fernández-Aguilar JL, et al. Transfusion requirements during liver transplantation: impact of a temporary portacaval shunt. *Transplant Proc*. 2006;38(8):2486-2487. https://doi.org/10.1016/j.transproceed.2006.08.045
57. Sun K, Hong F, Wang Y, et al. Venovenous bypass is associated with a lower incidence of acute kidney injury after liver transplan-

tation in patients with compromised pretransplant renal function. *Anesth Analg*. 2017;125(5):1463-1470. https://doi.org/10.1213/ANE.0000000000002311

58. Vieira de Melo PS, Miranda LEC, Batista LL, et al. Orthotopic liver transplantation without venovenous bypass using the conventional and piggyback techniques. *Transplant Proc*. 2011;43(4):1327-1333. https://doi.org/10.1016/j.transproceed.2011.03.061
59. Widmer JD, Schlegel A, Ghazaly M, et al. Piggyback or cava replacement: which implantation technique protects liver recipients from acute kidney injury and complications?: liver transplantation. *Liver Transpl*. 2018;24(12):1746-1756. https://doi.org/10.1002/lt.25334
60. Wu YM, Voigt M, Rayhill S, et al. Suprahepatic venacavaplasty (cavaplasty) with retrohepatic cava extension in liver transplantation: experience with first 115 cases. *Transplantation*. 2001;72(8):1389-1394. https://doi.org/10.1097/00007890-200110270-00010
61. Oliver CM, Fabes J, Ingram N, et al. Not all piggybacks are equal: a retrospective cohort analysis of variation in anhepatic transcaval pressure gradient and acute kidney injury during liver transplant. *Exp Clin Transplant*. 2021;19(6):539-544. https://doi.org/10.6002/ect.2021.0050
62. Fabes J, Spiro M, Research Group RFP. Prospective cohort study assessing the use of peripheral saphenous venous pressure monitoring as a marker of the transcaval venous pressure gradient in liver transplant surgery. *Exp Clin Transplant*. 2021;19(12):1291-1297.
63. Fonouni H, Mehrabi A, Soleimani M, Müller SA, Büchler MW, Schmidt J. The need for venovenous bypass in liver transplantation. *HPB (Oxford)*. 2008;10(3):196-203. https://doi.org/10.1080/13651820801953031
64. Reddy K, Mallett S, Peachey T. Venovenous bypass in orthotopic liver transplantation: time for a rethink? *Liver Transpl*. 2005;11(7):741-749.
65. Chari RS, Gan TJ, Robertson KM, et al. Venovenous bypass in adult orthotopic liver transplantation: routine or selective use? *J Am Coll Surg*. 1998;186(6):683-690. https://doi.org/10.1016/s1072-7515(98)00101-x
66. Oken AC, Frank SM, Merritt WT, et al. A new percutaneous technique for establishing venous bypass access in orthotopic liver transplantation. *J Cardiothorac Vasc Anesth*. 1994;8(1):58-60. https://doi.org/10.1016/1053-0770(94)90013-2

How to cite this article: Shaker TM, Eason JD, Davidson BR, et al. Which cava anastomotic techniques are optimal regarding immediate and short-term outcomes after liver transplantation: A systematic review of the literature and expert panel recommendations. *Clin Transplant*. 2022;36:e14681. https://doi.org/10.1111/ctr.14681