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Modified cavocavostomy technique for deceased donor liver transplantation

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Abstract

Rationale. *The refinement of liver transplantation technique, the development and implementation of new surgical technologies into clinical practice, including those for inferior vena cava reconstruction, are important for the improvement of surgery outcomes.*

The study purposes *were to present our own modification of cavocavostomy and options for its technical implementation in deceased donor liver transplantation, as well as to study the clinical effects and the impact of new surgical technique on the outcomes.*

Material and methods. *A retrospective, single-centre study included the data from 109 consecutive deceased donor liver transplantations performed between 2012 and 2021. In 106 procedures, inferior vena cava reconstruction was performed either according to the classic technique (group 1, n=23, 22%), or using our own modification of cavocavostomy* *(group 2, n=83, 78%). To assess the clinical efficacy and safety of the new surgical technique, we compared the characteristics of donors and recipients, intraoperative parameters, features of early postoperative course, incidence of surgical complications, initial function, immediate and long-term graft survival. Three piggyback procedures were not included in the comparative analysis.*

Results. *Two groups were generally comparable in terms of the characteristics of donors and recipients, however, the classic inferior vena cava was significantly more often used during transplants for unresectable parasitic liver lesions (17% vs. 1%, p=0.008) and retransplantations (30% vs. 5%, p=0.002). There were no statistically significant differences in the main intraoperative parameters between groups 1 and 2. The duration of transplantations was 8.0 h (interquartile range: 6.5–8.5 h) and 7.0 h (interquartile range: 6.0–8.0 h), p=0.112; anhepatic phase lasted 70 min (interquartile range: 60–75 min) and 70 min (interquartile range: 59–90 min), p=0.386; warm ischemia time was 45 min (interquartile range: 38–52 min) and 45 min (interquartile range: 38–50 min), p=0.690; inferior vena cava was clamped for 47 min (interquartile range: 40–55 min) and 50 min (interquartile range: 40–55 min), p=0.532. The volumes of intraoperatively transfused blood components were, respectively: packed red cells 630 ml (interquartile range: 0–1280 ml) and 600 ml (interquartile range: 0–910 ml), p=0.262; blood reinfusion 770 ml (interquartile range: 360–1200 ml) and 700 ml (interquartile range: 0–1200 ml), p=0.370; fresh frozen plasma 2670 ml (interquartile range: 2200 and 3200 ml) and 2240 ml (interquartile range: 1880–2900 ml), p=0.087.*

When using classic caval reconstruction technique, the proportion of grafts with early dysfunction was higher: 44% vs. 17% (p=0.011), due to the higher rate of retransplantations in this group. The incidence of acute *kidney injury (by RIFLE ≥ I) was 35% and 19% (p=0.158), the need for renal replacement therapy was 22% and 15% (p=0.520) in group 1 and group 2, respectively. The total incidence of surgical complications in the early postoperative period was 30% and 16%, p=0.110.*

Conclusions. *The proposed technique of cavocavostomy can be considered as a priority method for caval reconstruction during deceased donor liver transplantation, with the exception of specific indications for the use of the classic technique (retransplantation, involvement of the inferior vena cava wall in a parasitic process or presentation of a tumor node to it, as well as in cases of widespread adhesive process in the abdominal cavity, hypertrophy of the segment 1 of the native liver, the presence and location of TIPS, thinning of the wall of the retrohepatic inferior vena cava, the risk of graft compression with its large size).*

The choice of the cavocavostomy variant should be carried out taking into account the size ratio of the graft to the recipient's right subdiaphragmatic space, and the topography features of the recipient's hepatic veins.

Keywords: liver transplantation, inferior vena cava reconstruction, cavocavostomy

Conflict of interests Authors declare no conflict of interest

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ADQI Group, Acute Dialysis Quality Initiative Group

AKI, acute kidney injury

ALT alanine aminotransferase

AST, aspartate aminotransferase

BD, brain death

BMI, body mass index

EAD, early allograft dysfunction

FFP, fresh frozen plasma

GFR, glomerular filtration rate

HCC, hepatocellular carcinoma

IQR, interquartile range

IVC, inferior vena cava

IVC, inferior vena cava

LC, liver cirrhosis

LC, liver cirrhosis

MELD/MELD Score, Model For End-Stage Liver Disease

MELD-Na, MELD-Na Score for Liver Cirrhosis. Adds sodium to the MELD model for liver cirrhosis

MLV, mechanical lung ventilation

PBC, primary biliary cirrhosis

PBCh, primary biliary cholangitis

PNF, primary non-function graft

RIFLE classification, a newly developed international consensus classification for acute kidney injury, defines three grades of severity – risk (class R), injury (class I) and failure (class F) – but has not yet been evaluated in a clinical series

RRT, renal replacement therapy

TBI, traumatic brain injury

TIPS, transjugular intrahepatic portosystemic shunt

Introduction

In the decades since the first attempts at human liver transplantation, this technology has come a long way from an almost hopeless intervention in hopeless patients to a standard of care for end-stage liver disease with no comparable therapeutic alternatives. Of course, the results achieved would not have been possible without solving many issues related to anesthesia and intensive care, the introduction of new immunosuppression regimens, the use of antibacterial, antifungal and antiviral drugs, extracorporeal detoxification methods, laboratory and instrumental diagnostic tests. However, the decisive role in the success of transplantation, as before, is precisely the surgical stage of treatment. To date, most of the technical aspects of liver transplantation have been studied in great detail, many centers use clear algorithms and standards for performing the operation in their practice. However, this does not mean that the potential for further improvement of surgical technique has been completely exhausted.

To date, a number of different methods have been proposed to restore the blood outflow from the graft. So, historically, the first variant of caval-caval reconstruction was the technique described by T. E. Starzl et al. [1] in 1963 and involving the implementation of hepatectomy with the resection of the retrohepatic inferior vena cava (IVC) and making two anastomoses above and below the liver graft in an "end-to-end" type between the IVC of the donor and the IVC of the recipient, which was called "classical".

Five years later, in 1968, R.Y. Calne and R. Williams [2] presented the first clinical case of liver transplantation with preserving the recipient's retrohepatic IVC and the use of the recipient's united orifices of the recipient's hepatic veins for anastomosis with the donor's suprahepatic IVC. In 1989, A. Tzakis, S. Todo and T. E. Starzl [3], based on the material of 24 operations performed in Pittsburgh within four months, presented a detailed description of the caval reconstruction technique with preserving the retrohepatic part of recipient's IVC, and using both all three combined orifices of the hepatic veins for anastomosis, and variants with joining only the right and middle or middle and left hepatic veins. This reconstruction technique was given the original name "*piggyback*" by the authors, which in Oxford English Dictionary is interpreted as *"a ride on someone's back, while he or she is walking"*.

In 1992, J. Belghiti et al. [4] described another method of caval-caval reconstruction in liver transplantation: side-to-side anastomosis between the IVC of the donor and the recipient.

Today, each of these caval reconstruction options can be performed without the use of a veno-venous bypass or temporary bypass. This is partly why the question of choosing the best option for restoring venous outflow is still debatable and is a topical subject of research. Of particular importance are the issues of minimizing the risks of surgical complications associated with caval reconstruction, primarily venous outflow disorders, as well as the frequency and severity of acute kidney injury (AKI). An analysis of the results of published studies allows us to conclude that when using different reconstruction options, the incidence of AKI is approximately the same, and the risks of impaired venous outflow are slightly higher when performing side-to-side anastomosis and are comparable when using the *piggyback* and classical technique (Fig. 1).

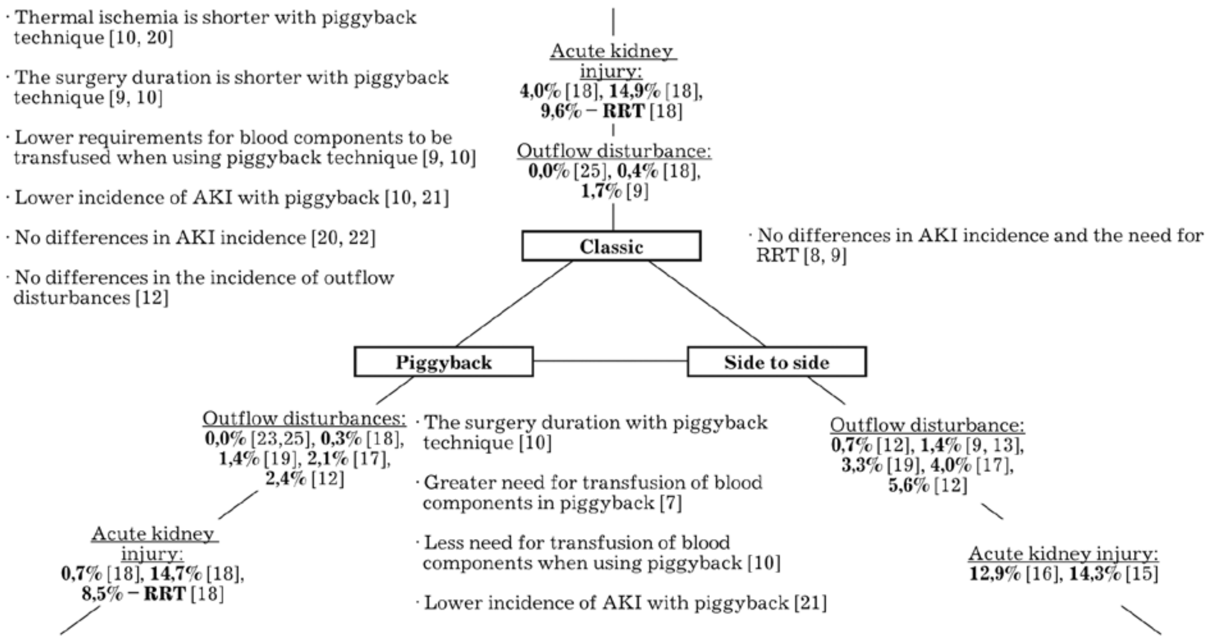

Fig. 1. The incidence of individual complications when using classic caval reconstruction, traditional piggyback technique and side-to-side anastomosis in liver transplantation from a deceased donor

It is necessary to pay attention to several more modifications of the caval-caval reconstruction technique involving the preservation of the recipient's retrohepatic IVC. In 2001 Y.M. Wu et al. [5] analyzed 115 consecutive liver transplantations, in which they used their own modification of the caval reconstruction technique, in which, after hepatectomy with preservation of the retrohepatic part of the IVC under conditions of its complete clamping, the orifices of three hepatic veins were united with an additional dissection of the anterior surface of the vein until a wide triangular opening was formed. The donor's IVC was also dissected downwards until a hole of the appropriate size was formed. The anastomosis was made using a continuous suture.

In 2006, D. Dasgupta et al. [6] presented a description of their own modifications of the caval-caval reconstruction: (1) *triangular cavocavostomy* and (2) *self-triangulating cavocavostomy*. In the first option, during hepatectomy, two clamps are applied to the recipient's

IVC: over the hepatic veins from above, over the renal veins from below, the orifices of the hepatic veins are united and, additionally, the recipient's IVC is dissected downwards along the anterior surface at 6-8 cm. The donor's IVC is also dissected along the anterior surfaces from top to bottom. If the length of the donor's IVC is not large, then the vein is cut completely, but usually it is necessary to cut about 2/3 of the donor IVC. The cavocaval anastomosis has the shape of a triangle, with each of the three sides to be sutured from the outside, which the authors consider to be a significant advantage of the proposed technique. After the start of blood flow through the portal vein, the preservation solution displaced by portal blood from the organ, is poured out through an unplugged infrahepatic end of the donor IVC or, if it was completely dissected, then through a specially left hole in the anastomosis. Next, the outflow is blocked, the clamps are removed from the IVC and the anastomosis is sealed.

The second modification differs in that during hepatectomy, the orifices of all hepatic veins are sutured; below the level of their confluence with the IVC, a partial lateral release of the vein is undertaken and a longitudinal cavotomy 6-8 cm long is performed. Preparation of the donor IVC is made in the same way as in *triangular cavocavostomy*, however, the IVC is dissected downward at 4-6 cm, and the infrahepatic end of the vein is shortened so that its length from the edge of the liver does not exceed 5 mm. Next, the walls of the anastomosis are formed from the outside with a suture on the right and left. Reperfusion is carried out in the same way as in the first modification.

In our own program of liver transplantation from a deceased donor, when performing reconstruction of the venous outflow structure, we strive to preserve the retrohepatic IVC and perform the original modification of caval reconstruction, i.e. a wide cavocavostomy in several options. In cases where hepatectomy with preserving the retrohepatic IVC is associated with a high risk of bleeding or is not surgically feasible, caval-caval reconstruction is performed according to the classical technique.

The purpose of this work is to present, in our opinion, the optimal modification of caval-caval reconstruction with preserving the IVC during liver transplantation from a deceased donor, to study its clinical effects and impact on surgical outcomes.

Material and methods

Study design

This single-centre, retrospective study included the data on the characteristics and outcomes of 109 consecutive deceased donor liver transplants performed between May 2012 and March 2021. In three cases, caval-caval reconstruction was performed using the *piggyback technique*. Due to the small number of such operations, a cohort of 106 cases was formed for analysis and divided into two groups depending on the technique of forming the cavocaval anastomosis: in group 1 (n=23, 22%) a "classical technique" was used, in group 2 (n=83, 78%) "cavocavostomy" was applied.

The groups were compared according to a list of parameters reflecting the preoperative patient condition, the characteristics of donors and grafts, the characteristics and course of operations, the initial function of transplanted organs, as well as the immediate and long-term graft survival.

Main characteristics of the study cohort

The age of operated patients ranged from 24 to 68 years (median 49 years). The leading indications for transplantation were: liver cirrhosis

(LC) in the outcome of viral hepatitis (n=32, 30%), hepatocellular carcinoma amid LC (n=26, 25%), LC in the outcome of cholestatic diseases (n=12, 11%), LC of unclear etiology (n=12.11%), unresectable parasitic liver lesion (n=5.5%), 11 (10%) cases were repeated transplantations. The median values of the prognostic indices MELD and MELD-Na on the date of transplantation were 15 (from 7 to 40) and 17 (from 7 to 40), respectively. Fourteen (13%) patients were classified as Child-Pugh class A, 47 (44%) were class B, and 41 (39%) were class C. All liver grafts were obtained under conditions of multi–organ harvesting from postmortem donors aged 20 to 63 years (median 46 years) with ascertained brain death, which occurred as a result of severe traumatic brain injuries (n=21, 20%) or an acute cerebrovascular accident (n=82, 80%). In all cases, prior to transplantation, the donor organ was preserved and transported under conditions of static hypothermic preservation in a histidine-tryptophan-ketoglutarate solution. The cold ischemia time varied from 2 to 15 hours (median 8 hours).

The choice of the caval reconstruction type, an original modification of the cavocaval anastomosis, principles and options for its formation

The vast majority of transplantations were performed under conditions of complete clamping of the recipient's IVC without using a veno-venous bypass; vascular clamps were applied cranially to the orifices of the hepatic veins and renal veins, respectively.

In transplantations for liver unresectable parasitic lesions with the involvement of the IVC wall in the pathological process, in retransplantations in the long-term, as well as in case of technical difficulties and a high risk of a significant increase in blood loss due to severe hypertrophy of segment 1, a considerably thinned wall of the retrohepatic IVC, a widespread adhesive process after previously undergone interventions, and, in some cases, a previously installed transjugular intrahepatic portosystemic shunt (TIPS), the preference was given to the classic caval-caval reconstruction.

In all other cases, when hepatectomy could be performed without marked technical difficulties and within an acceptable time frame, i.e. did not lead to a significant additional prolongation of the cold ischemia time, the retrohepatic IVC was sought to keep preserved.

Our original modification of the caval-caval reconstruction in general consisted of anastomosing the longitudinally dissected IVC of the liver donor with the anterior or anterolateral wall of the recipient's IVC. Depending on a number of conditions, i.e. the variants of the relative position of the orifices of the recipient's right, middle and left hepatic veins, their proximity to the caval opening of the diaphragm, the size ratio of the graft to the recipient's abdominal cavity, three options for such reconstruction were proposed and applied in clinical practice:

Option 1: if the graft size corresponded to the size of the abdominal cavity upper floor and the location of the orifices of the three hepatic veins were approximately at the same level, their orifices were dissected and united with the lumen of the IVC, which was dissected downward along the anterior surface strictly in the center with the excision of the wall in the form of a triangle with a caudally directed top. The excess orifices of the hepatic veins were excised in the cranial direction until a straight line of the IVC wall had been obtained, parallel to the diaphragm (Fig. 2A, 3B).

Option 2: if the dimensions of the right subdiaphragmatic space significantly exceeded the dimensions of the right lobe of the donor liver, then to prevent its possible rotation, the anastomosis twisting or the IVC kink, a window in the recipient's IVC was cut out with the transition to the right-side wall of the vein in the form of an unequal triangle with its apex facing the right lateral wall of the IVC (Fig. 2B).

Option 3: in case of a pronounced disparity between the levels of confluence of the hepatic vein orifices, when the sites of confluence of the middle and left hepatic veins were significantly higher and laterally to the orifice of the right hepatic vein, the latter was excised with the transition of the incision to the anterior and right lateral walls of the IVC until a wide window was formed. The orifices of the middle and left hepatic veins were closed tightly with a continuous suture (Fig. 2C, 4B).

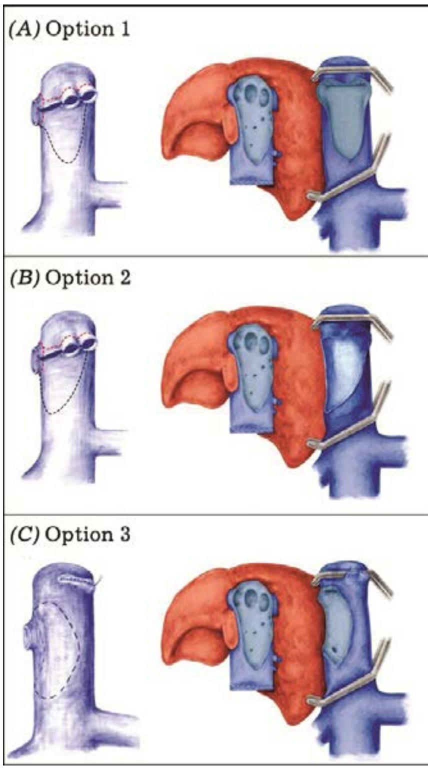

Fig. 2. The recipient's inferior vena cava preparation to perform modified cavocavostomy in various options: (A) joining three hepatic veins and excision of an inferior vena cava wall fragment along the anterior surface; (B) joining three hepatic veins and excision of an inferior vena cava wall fragment along the anterior and right lateral sides; (C) inclusion in the anastomosis of the orifice of only the right hepatic vein with excision of an inferior vena cava fragment along its anterior and right lateral walls. Explanation is in the text.

The donor's liver IVC was prepared in the same way under conditions of ongoing static hypothermic preservation and did not differ with regard to the cavocavostomy option. The posterior wall of the donor IVC fragment, its proximal and distal ends were isolated from the surrounding tissues, the diaphragm tissues and the cranial excess of the IVC and/or the right atrium were dissected, not reaching the orifices of the hepatic veins by at least 5 mm; small tributaries and possible defects were identified, and they were sutured. The mouths of the hepatic veins were inspected. The distal end of the donor IVC was tightly sutured with a 4/0 polypropylene suture or a stapler with a vascular cassette. Further, the proximal end of the IVC was dissected along the strictly centered caudal direction, not reaching 1–2 cm from the sutured distal end of the IVC. Additionally, a partial excision of the posterior wall of the IVC was performed in such a way that a wide opening was formed in the form of a conditional triangle, with its apex facing the distal end of the vein (Fig. 2 A-C, 3A, 4A).

When performing a modified cavocavostomy, the graft was placed to the right of the recipient IVC. The anastomosis was directly formed with two 4/0 polypropylene sutures: its posterior wall was sutured from the inside, and the anterior wall was done from the outside, according to the technique we proposed earlier [26]. Intraoperative photographs of the modified cavocavostomy are shown in Fig. 3 (option 1) and Fig. 4 (option 3).

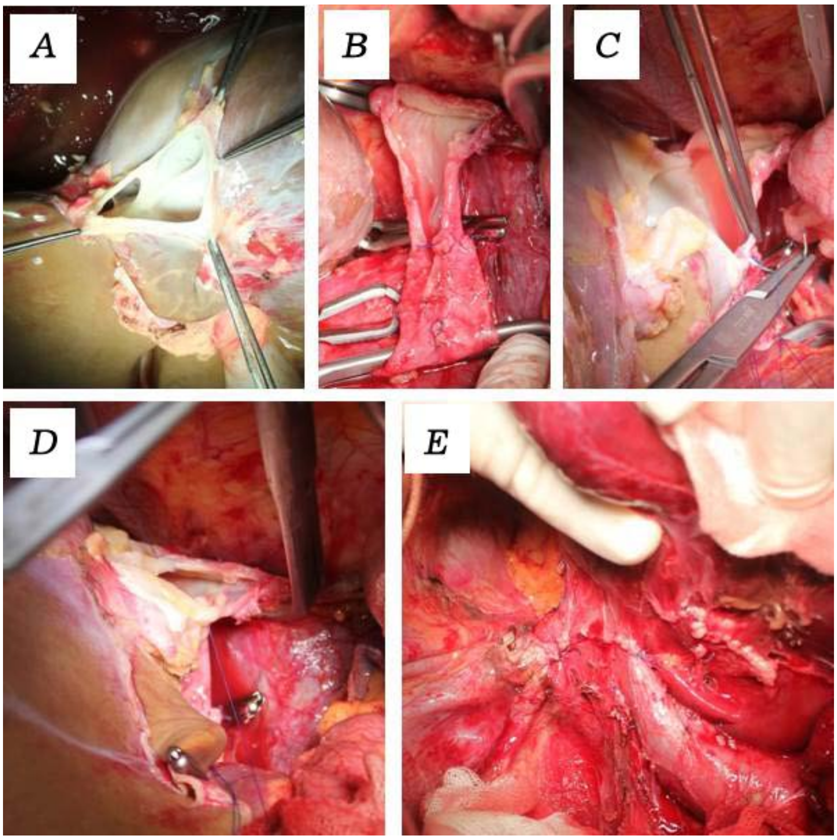

Fig. 1. Modified cavocavostomy – option 1. Preparation of the graft inferior vena cava and recipient's inferior vena cava, stages of forming the anastomosis: (A): the inferior vena cava of the graft prepared for cavocavostomy; (B) the recipient's inferior vena cava after hepatectomy - a wide window was formed with the inclusion of the orifices of three hepatic veins and excision of an inferior vena cava wall fragment along the anterior surface; (C) the right wall of the anastomosis was formed with a continuous suture from the inside of the inferior vena cava lumen; (D) forming the left wall of the anastomosis; (E) final view of the cavocavostomy.

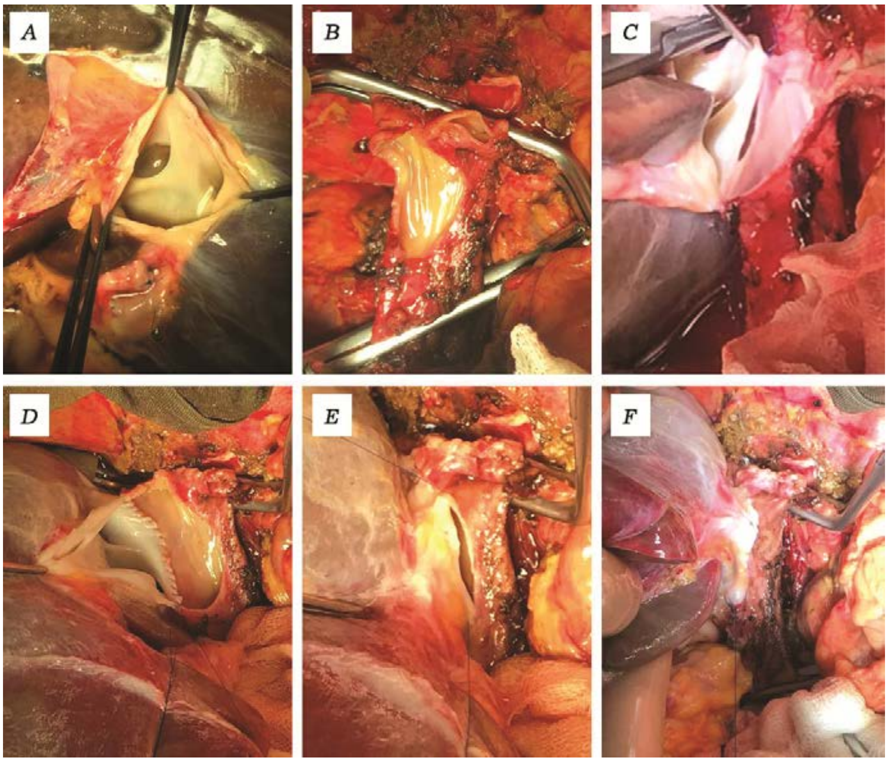

Fig. 2. Modified cavocavostomy − option 3. Preparation of the inferior vena cava of the graft and the inferior vena cava of the recipient, stages of anastomosis formation: (A) the inferior vena cava of the graft prepared for performing cavocavostomy; (B) the inferior vena cava of the recipient after hepatectomy − a wide window was formed with the inclusion of the orifice of the right hepatic vein and excision of an inferior vena cava wall fragment along the anterior and right lateral surface; (C) the graft is placed in the wound, traction sutures are applied − the beginning of the anastomosis formation; (D) the right wall of the anastomosis was formed with a continuous suture from the inside of the inferior vena cava lumen; (E) the start of forming the left wall of the anastomosis; (F) the final view of the cavocavostomy

The criteria and definitions used

To record clinically important conditions and outcomes, the generally accepted definitions and validated criteria were used:

Reperfusion syndrome: a drop in mean arterial pressure by more than 30% below the baseline level, exceeding one minute in duration and developing within the first five minutes after liver graft reperfusion [27].

Early allograft dysfunction (EAD): AST or ALT level higher than 2000 U/L in the period between 24 h and 7 days post-transplant and/or INR ≥ 1.60 on post-transplant day 7 and/or total bilirubin concentration ≥ 10 mg/dl (≥ 171 μmol/L) on day 7 after transplantation [28].

Primary non-function graft (PNF) in a retrospective assessment included transplanted organs with a severe (irreversible) form of *EAD*, lost (retransplantation or death of the recipient) without a function recovery within the first month after surgery for reasons unrelated to surgical complications (thrombosis, biliary complications, bleeding, etc.) or acute rejection.

Acute kidney injury (AKI) was diagnosed and staged based on changes in serum creatinine concentration according to the RIFLE criteria [29] proposed by Acute Dialysis Quality Initiative (ADQI) Group, in the interval from 24 hours after the completion of transplantation to the seventh postoperative day inclusive.

Statistical data processing

Quantitative variables were presented as a median, additionally indicating either the minimum and maximum values when exactly they represented clinical significance, or giving the interquartile range. For qualitative features, absolute frequencies and relative frequencies expressed as a percentage were indicated. The significance of differences in quantitative and qualitative variables in two independent samples was determined using the nonparametric two-tailed Mann-Whitney test and two-tailed Fisher's exact test, respectively. Differences were considered statistically significant at $p<0.050$. Survival was calculated using the Kaplan-Meier method with 95% confidence intervals. Differences in survival between two independent groups were assessed using the Log-rank test and were considered statistically significant at $p<0.050$.

Calculations were performed using the statistical software package Statistica 12 (StatSoft Inc., USA).

Results

Due to the fact that when performing operations in our case series, the choice of the caval reconstruction method was not randomized, but was based on the principles outlined above, the proportion of patients with parasitic liver lesions and previous liver transplantation was statistically significantly higher in the group where the classic technique was used. Nevertheless, the compared groups were comparable in other preoperative characteristics of recipients, parameters of donors and organs (Table 1).

Table 1. Preoperative characteristics of recipients, information about deceased donors and grafts

Parameter	Group 1. Classic technique, n=23	Group 2. Cavocavostomy, n=83	p
Preoperative characteristics of recipients			
Age, years	42 (24;68)	50 (24;67)	0.097
Male gender, n (%)	16 (70)	55 (66)	1,000
BMI, kg/m^2	24.7 (17.6;32.3)	25.8 (14.8;38.6)	0.361
Re-transplantation, n (%)	7 (30)	4 (5)	**0.002**
Urgent status, n (%)	1 (4)	4 (5)	1,000
LC of viral etiology, n (%)	3 (13)	29 (35)	0.070
HCC against the background of LC, n (%)	5 (22)	21 (25)	1,000
PBC/PSCh, n (%)	1 (4)	11 (13)	0.456
Parasitic liver diseases, n (%)	4 (17)	1 (1)	**0.008**
MELD*, score	18 (10;35)	15 (7;40)	0.100
MELD-Na*, score	20 (10;35)	17 (7;40)	0.074
Child-Pugh Class C, n (%)	8 (35)	33 (40)	0.810
GFR according to MDRD, ml/min/ 1.73m^2	90 (35;179)	92 (33;166)	0.790
Characteristics of deceased donors and grafts			
Age, years	43 (20;62)	46 (20;63)	0.410
Male sex, n (%)	17 (74)	52 (63)	0.459
TBI as the cause of BD, n (%)	5 (22)	16 (19)	0.773

MLV duration, days	2 (1;7)	2 (1;7)	0.318
Sodium, mmol/L	151 (135;178)	149 (124;177)	0.610
AST, U/L	30 (10;160)	30 (7;176)	0.927
Norepinephrine, n (%)	16 (70)	51 (61)	0.626
Norepinephrine dose, ng/kg/min	240 (10;1500)	300 (20;800)	0.646
Visual assessment of steatosis, n (%)			
- 0%	10 (44)	25 (30)	>0.05
- up to 30%	13 (56)	56 (68)	
- 30%–50%	-	2 (2)	
- more than 50%	-	-	
Cold ischemia time, h	9.0 (4.5;12.5)	8.0 (2.0;15.0)	0.268

Notes: - excluding patients with parasitic liver disease. BMI, body mass index; LC, liver cirrhosis; HCC, hepatocellular carcinoma; PBC, primary biliary cirrhosis; PBCh, primary biliary cholangitis; GFR, glomerular filtration rate; TBI, traumatic brain injury, BD, brain death; MLV, mechanical lung ventilation, AST, aspartate aminotransferase.*

The most important characteristics of operations and the intraoperative period are presented in Table. 2.

Table 2. Intraoperative period characteristics

Parameter	Group 1. Classic technique, n=23	Group 2. Cavocavostomy, n=83	p
Temporal characteristics of transplants			
Surgery duration, h	8.0 (6.5;8.5)	7.0 (6.0;8.0)	0.112
Anhepatic phase, min	70 (60;75)	70 (59;90)	0.386
Warm ischemia time, min	45 (38;52)	45 (38;50)	0.690
IVC clamping duration, min	47 (40;55)	50 (40;55)	0.532
Infusion-transfusion therapy, vasopressor support and diuresis			
Total volume of infusion, L	7.50 (5.80;9.03)	6.50 (5.58;8.00)	0.191
Packed red cells, L	0.63 (0.00;1.28)	0.60 (0.00;0.91)	0.262
Autologous blood reinfusion, L	0.77 (0.36;1.20)	0.70 (0.00;1.20)	0.370
FFP, L	2.67 (2.20;3.20)	2.24 (1.88;2.90)	0.087
Thromboconcentrate infusion, n (%)	3 (13)	6 (7)	0.404
Norepinephrine dose, ng/kg/min			
- liver mobilization	100 (0;200)	0 (0;100)	0.166
- anhepatic phase	600 (300;1200)	400 (200;700)	0.137
- graft reperfusion	1000 (600;2000)	900 (500;1400)	0.270
- surgery completion	400 (200;900)	300 (100;600)	0.201
Diuresis rate, ml/kg/h	1,6 (1.0;2.7)	1.3 (0.9;2.4)	0.608
Reperfusion syndrome, n (%)	5 (22)	12 (15)	0.520

Notes: IVC, inferior vena cava, FFP, fresh frozen plasma

Despite the absence of statistically significant differences across the entire list of analyzed characteristics of operations, the technique of performing caval anastomosis could potentially affect both the initial graft function and, in general, the course of the early postoperative period (Table 3).

Table 3. Clinical and laboratory characteristics of the immediate postoperative period, the initial graft function

Parameter	Group 1. Classic technique, n=23	Group 2. Cavocavostomy, n=83	p
First 24 hours after transplantation			
Arterial blood lactate, mmol/L			
- surgery completion/transfer to ICU	6.9 (5.0;8.2)	4.5 (2.8;7.1)	**0.003**
- 6 hours after surgery	4.7 (4.2;10.2)	3.8 (2.6;7.4)	**0.021**
- 12 hours after surgery	3.0 (2.2;3.7)	2.6 (1.7;4.0)	0.188
- 24 hours after surgery	1.9 (1.3;2.4)	1.7 (1.2;2.4)	0.317
AST, U/L	669 (423;2728)	467 (289;966)	0.058
ALT, U/L	645 (292;1328)	528 (273;843)	0.131
Creatinine, μmol/L	112 (81;171)	87 (71;130)	**0.037**
MELD after 24 hours, score	28 (24;33)	26 (24;31)	0.381
MLV for over 24 hours, n (%)	4 (17)	17 (21)	1.000
The need for vasopressor support for more than 24 hours, n (%)	9 (39)	23 (28)	0.313
Initial graft function, AKI (assessed on day 7 after transplantation)			
EAD, n (%)	10 (44)	14 (17)	**0.011**
PNF, n (%)	1 (4)	4 (5)	1.000
Peak AST/ALT, U/L	773 (544;3351)	619 (368;1124)	0.105
Total bilirubin, μmol/L	53 (26;102)	28 (19;63)	0.192
INR	1,1 (1.1;1.3)	1.1 (1.1;1.3)	0.467
Creatinine (max) μmol/L	108 (77;152)	89 (69;129)	0.077
AKI ≥ I graded by RIFLE, n (%)	8 (35)	16 (19)	0.158
The need for RRT, n (%)	5 (22)	12 (15)	0.520

In the early postoperative period, surgical complications developed in 7 (30%) patients of the first group and in 14 (17%) recipients of the second group, p=0.110. Repeated open surgery was required in 7 (30%)

and 11 (13%) cases, respectively, p=0.064. The structure of surgical complications is presented in Table. 4.

Table 4. Structure and incidence of surgical complications in the early postoperative period

Surgical complication	Group 1. Classic technique, n=23	Group 2. Cavocavostomy, n=83	p
Intra-abdominal bleeding/hematoma, n (%)	4 (18)	7 (8)	0.452
Biliary leak, n (%)	-	1 (1)	-
Hepatic artery thrombosis, n (%)	1 (4)	1 (1) left hepatic artery only	0.389
Intra-abdominal infection/peritonitis, n (%)	-	2 (2)	-
Wound infection, n (%)	2 (9)	2 (2)	0.205

In none of the cases, the cavocaval anastomosis was the source of bleeding. In most cases, during revision, diffuse blood oozing from tissues was noted due to coagulopathy. In none of the operated patients, ultrasound examinations revealed any significant disorders of the venous outflow from the graft, stenosis or kinking of caval anastomoses. Figures 5a and 5b show three-dimensional images of the recipient IVC in the area of the caval anastomosis during forming a wide cavocavostomy and during the classic caval reconstruction, respectively. Images were obtained by computed tomography with intravenous contrast enhancement. The imaging investigations were performed during the first 14 days after transplantation for the purpose of diagnostic search in fever of unknown origin.

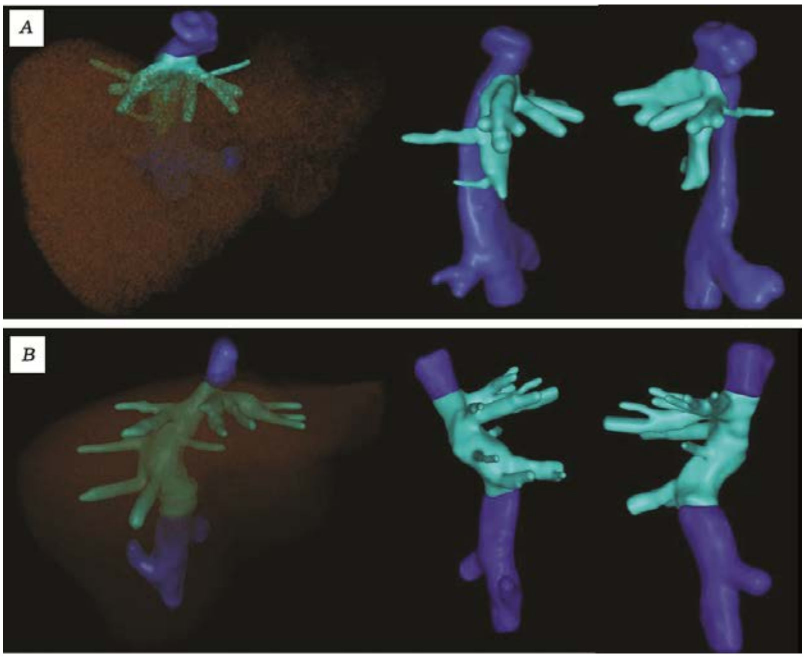

Fig. 3. Computed tomography imaging (3D reconstruction) of the caval-caval anastomosis at early stage after transplantation: (A) modified cavocavostomy – option 1; (B) classic technique: inferior vena cava of the recipient in blue color; the donor's inferior vena cava fragment in light-blue

The presented illustrations demonstrate clinical cases with intact geometry of cavocaval anastomoses and no signs of impaired outflow from the liver graft. However, when reviewing the archive of computed tomograms performed after liver transplantation of a deceased donor, we identified a case in which, during classical reconstruction, an anatomically significant stenosis of the proximal anastomosis to 11 mm in diameter was noted (Fig. 6).

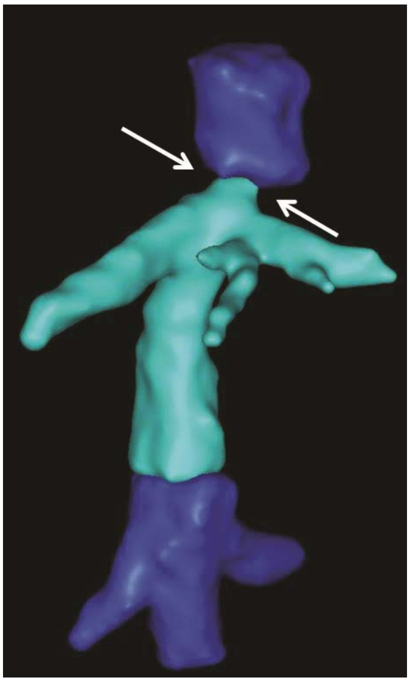

Fig. 4. Computed tomography imaging (3D reconstruction) at early stages after liver transplantation when performing caval-caval reconstruction according to the classic technique, white arrows indicate the proximal anastomosis stenosis at the level of the diaphragm

In this case, taking into account the satisfactory function of the graft, it was decided to refrain from any interventions in the area of anastomotic stenosis.

When analyzing the immediate and long-term graft survival, with regard to the chosen option of caval-caval reconstruction, no statistically significant differences were found (Fig. 7).

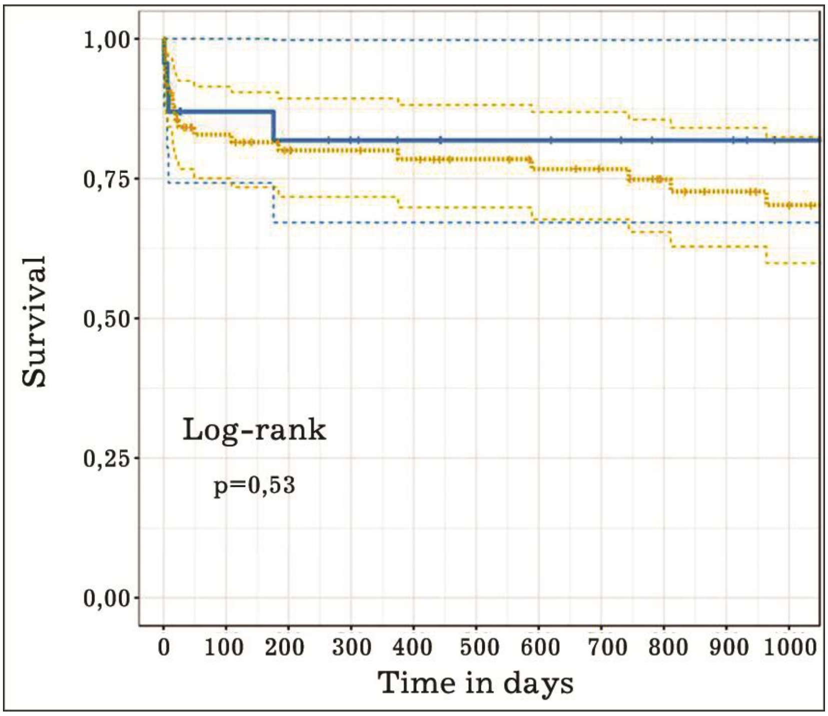

Fig. 7. Liver graft survival with regard to the option of the caval-caval reconstruction: blue graph indicates classic technique, yellow graph indicates cavocavostomy, dotted curves of the respective colors indicate 95% confidence intervals. There are no statistically significant differences

One of the advantages of removing the recipient's native liver with the resection of the retrohepatic IVC is the reduction of hepatectomy duration and graft cold ischemia time by means of avoiding the dissection stage between the anterior surface of the IVC and the liver parenchyma. However, the analysis of our own case series has shown that in the group where the classical technique of caval reconstruction was used the surgery duration and cold ischemia time were on average 1 hour longer than in the group where the retrohepatic IVC was preserved (differences are not statistically significant). This can be explained by the fact that the classic technique of caval reconstruction was used mainly in cases of widespread adhesions after previous surgical interventions and in the operations for extensive parasitic liver lesions involving anatomical structures adjacent to the liver. Preservation of the retrohepatic IVC in these cases would be accompanied by an even greater increase in the surgery duration and graft cold ischemia time, unacceptably high risks of damage to the IVC wall and massive bleeding, as well as the impossibility of performing a radical surgery if the IVC wall was involved in the parasitic process.

In our opinion, an important technical advantage of the proposed technique of a wide cavocavostomy over a traditional piggyback and side-to-side anastomosis is, first of all, a guarantee of no disturbances in the blood outflow disturbance from the graft, and a more reliable fixing of the transplanted liver preventing of its possible rotation, especially in cases when the depth of the right subdiaphragmatic space significantly exceeds the thickness of the right lobe of the donor organ.

Unlike the piggyback technique *and* side-to-side anastomosis of the donor and recipient IVC, the modified cavocavostomy involves complete clamping of the IVC, which can have a negative impact on systemic hemodynamic parameters. As well as when using the classic technique, we consider it fundamentally important to perform a trial clamping of the recipient IVC for 1-2 minutes. Such a maneuver allows the anesthesia team to assess the response of the recipient's cardiovascular system and, if necessary, adjust cardiotonic and vasopressor support, and volemic load. To date, the arsenal of anesthesia methods in liver transplantation allows performing operations under conditions of complete IVC clamping without using the veno-venous bypass. Extremely rarely, when critical hemodynamic instability can develop directly during making the caval-caval anastomosis, a possible option is to switch from complete clamping of the IVC to its partial lateral unclamping immediately after the completion of the anastomosis.

In the analyzed case series, the incidence of reperfusion syndrome was not associated with the method of caval reconstruction used, and made 22% and 15% in the first and second groups, respectively, $p=0.520$. We believe that the main risk factors for this complication are the prolonged graft cold and warm time, therefore, even with a smooth course of surgery before graft reperfusion, by the time blood flow has been started, the anesthetic team should be ready for the development of reperfusion syndrome.

An important aspect that largely determines the course of the early postoperative period is the development and severity of acute kidney injury. In the cohort under consideration, where all operations were performed under conditions of complete IVC clamping, the cumulative incidence of AKI of "Injury" severity and above, according to the RIFLE classification, was 28%, and the need for renal replacement therapy methods was 20%. Despite the fact that there were no statistically significant differences between the compared groups in terms of these parameters, the median creatinine level at 24 hours after surgery was significantly higher with classic caval-caval reconstruction: 112 µmol/L versus 87 µmol/L with cavocavostomy, $p=0.037$. However, by the end of the first postoperative week, the differences became statistically insignificant.

Considering that retransplantations were performed in the first group in 7 (30%) cases, a relatively high incidence of early graft dysfunction was quite an expected phenomenon and was not directly related specifically to the technique of forming the cavocaval anastomosis.

Separately, we should note that during caval reconstruction according to the method we have proposed, one anastomosis is performed, rather than two, as in the classical technique of cavocaval anastomosis, which, however, did not affect the duration of the graft warm ischemia time. This can be explained by the fact that the perimeter of the anastomosis at cavocavostomy is comparable to the total perimeter of two end-to-end anastomoses at classic reconstruction. Meantime, obviously, the area of the anastomosis of the recipient IVC and the graft IVC is much larger, which, in our opinion, is the fundamental advantage of the proposed method, which allows minimizing the risks of its compression and outflow disturbance after suturing the surgical wound. So, in one of three our cases, when the *piggyback* technique was used for caval-caval reconstruction with joining three hepatic veins, intraoperatively, an acute outflow disorder developed after graft reperfusion, which was manifested by an acutely developed liver edema. The cause of the complication was an insufficient area of the caval anastomosis. For emergency correction of this situation, an additional end-to-side cavocaval anastomosis was formed between the distal end of the donor IVC and the anterior wall of the recipient IVC under conditions of its lateral release without discontinue of the blood flow in the graft. Despite the facts that the performed maneuver was effective, the operation was completed without complications, and the postoperative period was uneventful, this case, in our opinion, clearly demonstrates the advantages of a wide cavocavostomy compared to the *piggyback technique.*

Thus, the results obtained allow us to conclude that the developed modification of the cavocaval anastomosis is a safe and effective method for reconstructing the venous outflow from a liver graft obtained from a deceased donor and can be performed in many patients. Nevertheless, in repeated transplantations, especially in the long term, in operations for parasitic liver damage, when the retrohepatic IVC or cavernal hilum is involved in the pathological process, as well as in segment 1 hypertrophy, priority should be given to the classical technique.

Conclusions

1. Modified cavocavostomy can be considered as a priority method for performing caval reconstruction in liver transplantation from a deceased donor, with the exception of specific indications for the use of the classic technique.

2. The choice of the cavocavostomy option is made taking into account the size ratio of the graft and the recipient's right subdiaphragmatic space, the topography specific features of the recipient's hepatic veins orifices.

3. The absolute indications for performing caval reconstruction by the classic technique should be considered the following: retransplantation in the long term, involvement of the wall of the inferior vena cava in a parasitic process or close contact with hepatocellular carcinoma node.

4. The method of caval reconstruction is ultimately chosen intraoperatively, taking into account the prevalence of the adhesive process in cases of previous surgical interventions, hypertrophy of the segment 1 of the patient's liver, the presence and location of TIPS, thinning of the wall of the retrohepatic inferior vena cava, the risk of graft compression with its large size.

5. The current level of anesthesiology advances, methods for monitoring and managing systemic hemodynamics makes it possible to refrain from other caval reconstruction methods that do not involve complete clamping of the inferior vena cava (*piggyback*, *side-to-side*) without increasing the risks of critical hemodynamic disruptions during the anhepatic period and of acute kidney injury after surgery. Refusal of these variants of caval reconstruction can be considered as the means to minimize the incidence of complications associated with the impaired blood outflow from the graft.

References

1. Starzl TE, Marchioro TL, Vonkaulla KN, Hermann G, Brittain RS, Waddell WR. Homotransplantation of the liver in humans. *Surg Gynecol Obstet.* 1963;117:659–676. PMID: 14100514.

2. Calne RY, Williams R. Liver transplantation in man. I. Observations on technique and organization in five cases. *Br Med J.* 1968;4(5630):535–540. PMID: 4881063 https://doi.org/10.1136/bmj.4.5630.535

3. Tzakis A, Todo S, Starzl TE. Orthotopic liver transplantation with preservation of the inferior vena cava. *Ann Surg.* 1989;210(5):649–652. PMID: 2818033 https://doi.org/10.1097/00000658-198911000-00013

4. 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. PMID: 1514163.

5. Wu YM, Voigt M, Rayhill S, Katz D, Chenhsu RY, Schmidt W, et al. Suprahepatic venacavaplasty (cavaplasty) with retrohepatic cava extension in liver transplantation: experience with first 115 cases. *Transplantation.* 2001;72(8):1389–1394. PMID: 11685109 https://doi.org/10.1097/00007890-200110270-00010

6. Dasgupta D, Sharpe J, Prasad KR, Asthana S, Toogood GJ, Pollard SG, et al. Triangular and self-triangulating cavocavostomy for orthotopic liver transplantation without posterior suture lines: a modified surgical technique. *Transpl Int.* 2006;19(2):117–121. PMID: 16441360 https://doi.org/10.1111/j.1432-2277.2005.00246.x

7. Lee TC, Dhar VK, Cortez AR, Morris MC, Winer LK, Silski LS, et al. Cincinnati Research on Outcomes and Safety in Surgery (CROSS). Impact of side-to-side cavocavostomy versus traditional piggyback

implantation in liver transplantation. *Surgery.* 2020;168(6):1060–1065. PMID: 32888712 https://doi.org/10.1016/j.surg.2020.07.041

8. Widmer JD, Schlegel A, Ghazaly M, Richie Davidson B, Imber C, Sharma D, et al. Piggyback or cava replacement: which implantation technique protects liver recipients from acute kidney injury and complications? *Liver Transpl.* 2018;24(12):1746–1756. PMID: 30230686 https://doi.org/10.1002/lt.25334

9. 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. PMID: 28410631 https://doi.org/10.1016/j.amjsurg.2017.03.045

10. Schmitz V, Schoening W, Jelkmann I, Globke B, Pascher A, Bahra M, et al. Different cava reconstruction techniques in liver transplantation: piggyback versus cava resection. *Hepatobiliary Pancreat Dis Int.* 2014;13(3):242–249. PMID: 24919606 https://doi.org/10.1016/s1499-3872(14)60250-2

11. Levi DM, Pararas N, Tzakis AG, Nishida S, Tryphonopoulos P, Gonzalez-Pinto I, 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. PMID: 22364695 https://doi.org/10.1016/j.jamcollsurg.2011.12.039

12. Navarro F, Le Moine MC, Fabre JM, Belghiti J, Cherqui D, Adam R, et al. Specific vascular complications of orthotopic liver transplantation with preservation of the retrohepatic vena cava: review of 1361 cases. *Transplantation.* 1999;68(5):646–650. PMID: 10507483 https://doi.org/10.1097/00007890-199909150-00009

13. Mehrabi A, Mood ZA, Fonouni H, Kashfi A, Hillebrand N, Müller SA, et al. A single-center experience of 500 liver transplants using

the modified piggyback technique by Belghiti. *Liver Transpl.* 2009;15(5):466–474. PMID: 19399735 https://doi.org/10.1002/lt.21705

14. Belghiti J, Ettorre GM, Durand F, Sommacale D, Sauvanet A, Jerius JT, et al. Feasibility and limits of caval-flow preservation during liver transplantation. *Liver Transpl.* 2001;7(11):983–987. PMID: 11699035 https://doi.org/10.1053/jlts.2001.28242

15. Hesse UJ, Berrevoet F, Troisi R, Pattyn P, Mortier E, Decruyenaere J, et al. Hepato-venous reconstruction in orthotopic liver transplantation with preservation of the recipients' inferior vena cava and veno-venous bypass. *Langenbecks Arch Surg.* 2000;385(5):350–356. PMID: 11026707 https://doi.org/10.1007/s004230000149

16. Cherqui D, Lauzet JY, Rotman N, Duvoux C, Dhumeaux D, Julien M, et al. Orthotopic liver transplantation with preservation of the caval and portal flows. Technique and results in 62 cases. *Transplantation.* 1994;58(7):793–796. PMID: 7940712

17. Parrilla P, Sánchez-Bueno F, Figueras J, Jaurrieta E, Mir J, Margarit C, et al. Analysis of the complications of the piggy-back technique in 1,112 liver transplants. *Transplantation.* 1999;67(9):1214–1247. PMID: 10342311 https://doi.org/10.1097/00007890-199905150-00003

18. Chen Z, Ju W, Chen C, Wang T, Yu J, Hong X, et al. Application of various surgical techniques in liver transplantation: a retrospective study. *Ann Transl Med.* 2021;9(17):1367. PMID: 34733919 https://doi.org/10.21037/atm-21-1945

19. Němec P, Ondrásek J, Nicovský J, Studeník P, Hökl J, Wagner R, et al. Význam piggyback techniky pri rekonstrukci venózního odtoku pri transplantaci jater [The piggyback technique in venous outflow tract reconstruction in liver transplantation]. *Rozhl Chir.* 2001;80(2):62–66. (In Czech.). PMID: 12881917

20. Nikeghbalian S, Toutouni MN, Salahi H, Aliakbarian M, Malekhosseini SA. A comparative study of the classic and piggyback techniques for orthotopic liver transplantation. *Electron Physician.* 2014;6(1):741–746. PMID: 25763139 https://doi.org/10.14661/2014.741-746

21. Cabezuelo JB, Ramirez P, Acosta F, Torres D, Sansano T, Pons JA, 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. PMID: 12962846 https://doi.org/10.1016/s0041-1345(03)00598-0

22. Brescia MD, Massarollo PC, Imakuma ES, Mies S. Prospective randomized trial comparing hepatic venous outflow and renal function after conventional versus piggyback liver transplantation. *PLoS One.* 2015;10(6):e0129923. PMID: 26115520 https://doi.org/10.1371/journal.pone.0129923

23. Massarollo PCB, Coelho FF, Brescia MDG, Sandoli Baía CE, Lallée MP, Dias de Almeida M, et al. Long-term outcome of a modified piggyback liver transplantation technique using the recipient's right and middle hepatic veins. *Transplant Proc.* 2020;52(5):1308–1311. PMID: 32247596 https://doi.org/10.1016/j.transproceed.2020.02.039

24. Lerut J, Ciccarelli O, Roggen F, Laterre PF, Danse E, Goffette P, 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. PMID: 12777866 https://doi.org/10.1097/01.TP.0000061613.66081.09

25. Vieira de Melo PS, Miranda LE, Batista LL, Neto OC, Amorim AG, Sabat BD, et al. Orthotopic liver transplantation without venovenous bypass using the conventional and piggyback techniques. *Transplant*

Proc. 2011;43(4):1327–1333. PMID: 21620122 https://doi.org/10.1016/j.transproceed.2011.03.061

26. Onopriev VI, Voskanyan SE, Artemyev AI, Evdokimov VA. *Method of great vessel anastomosis.* Patent № 2329772 C2 Russian Federation. Published July 27, 2008. Bull. № 21. Available at: https://patenton.ru/patent/RU2329772C2.pdf [Accessed April 1, 2022].

27. Aggarwal S, Kang Y, Freeman JA, Fortunato FL, Pinsky MR. Postreperfusion syndrome: cardiovascular collapse following hepatic reperfusion during liver transplantation. *Transplant Proc.* 1987;19(4 Suppl 3):54–55. PMID: 3303534

28. Olthoff KM, Kulik L, Samstein B, Kaminski M, Abecassis M, Emond J, et al. Validation of a current definition of early allograft dysfunction in liver transplant recipients and analysis of risk factors. *Liver Transpl.* 2010;16(8):943–949. PMID: 20677285 https://doi.org/10.1002/lt.22091

29. Bellomo R, Ronco C, Kellum JA, Mehta RL, Palevsky P. Acute dialysis quality initiative workgroup. Acute renal failure – definition, outcome measures, animal models, fluid therapy and information technology needs: the Second international consensus conference of the Acute Dialysis Quality Initiative (ADQI) group. *Crit Care.* 2004;8(4):R204–212. PMID: 15312219 https://doi.org/10.1186/cc2872

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