Modified Meso-Rex bypass with umbilical vein recanalization and intra-operative stenting

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Abstract
Purpose The aim of the study was to evaluate the usefulness of a novel modified Meso-Rex bypass surgical technique with umbilical vein recanalization and intra-operative stenting to treat portal vein cavernous transformation.

Methods In total, 13 portal vein cavernous transformation patients underwent Meso-Rex bypass surgery, consisting of bypass grafts between the superior mesenteric vein (SMV) and the recess of Rex as well as through the ligamentum teres hepatitis without stent implantation (Group A, n = 9) and umbilical vein recanalization with intra-operative stent implantation (Group B, n = 4).

Results In Group A, the bypass diameter was 0–6 mm (median 3 mm) and blood flow velocity 25–115 cm/s (median 72 cm/s) 1 month after Meso-Rex bypass surgery, with open bypass times of 0–67 months (median 6 months); 6 patients in this group developed postoperative Meso-Rex bypass occlusions. A patient in Group A treated with ligamentum teres hepatitis recanalization needed a thrombectomy and stent implantation during a second surgery 2 days after the Meso-Rex bypass, because of bypass thrombosis and umbilical vein stenosis. In Group B, the average modified Meso-Rex bypass diameter was 5.5–6.5 mm (median 6 mm), and the bypass vessels remained open in all patients, with blood flow rates of 45–100 cm/s (median 76.5 cm/s) 1 month after the modified Meso-Rex bypass, up to the endpoint (15–33 months, median 24 months). The rate of bypass occlusions in Group A and Group B were 22.2% and 0%, 30.0% and 0%, and 55.6% and 0% at 1 month, 3 months, and 1 year, respectively, after bypass surgery.

Conclusions Our novel modified Meso-Rex bypass approach for portal vein cavernous transformation treatment was effective with excellent long-term bypass patency.

Keywords Meso-Rex bypass · Portal vein cavernous transformation · Prehepatic portal hypertension · Umbilical vein recanalization · Intravascular stent

Introduction
Portal vein cavernous transformation (PVCT) often results in portal hypertension followed by gastrointestinal bleeding and is mainly caused by portal vein thrombosis of unknown etiology [1, 2]. The purpose of surgical intervention for PVCT and prehepatic portal hypertension patients is to create a conduit between the superior mesenteric vein (SMV) or splenic vein (SpV) and the left portal vein (LPV), through which mesenteric and SpV blood circumvents the varicose region and flows into the liver. The Meso-Rex bypass (MRB) has become a commonly used method in which a graft between the SMV and the recess of Rex bypasses the thrombosed portal trunk by using various shunt materials [3–6]. However, traditional MRB often requires dissection of the sagittal part of the portal vein (PV) [7], which can be challenging in patients with a severe adhesion. In addition, stent implantation or thrombolytic therapies have been deemed necessary to treat bypass embolizations or re-bleeding after MRB surgery [8–10]. Here we report a simpler modified MRB (mMRB) procedure comprising end-to-end anastomosis of an allograft vein from the SMV to the recanalized umbilical vein (UV), with intra-operative stent implantation from the opposite end covering the sagittal part of the portal vein-UV-allograft bypass. The aim was to evaluate this...
novel technique as a practical intervention procedure for the treatment of PVCT.

**Material and methods**

**Patients**

From November 2014 to June 2019, 13 patients with PVCT were enrolled in the study. Among them, 9 patients underwent traditional MRB including 1 patient with UV recanalization without stent implantation (Group A), and 4 PVCT patients underwent the new mMRB approach with UV recanalization and intra-operative stent implantation (Group B). Data from these patients were retrospectively reviewed. The follow-up endpoint was set as December 2020. Of the 13 patients, 9 were male and 4 were female, with a mean age of 36 years (range: 11–62 years). All patients had a history of gastrointestinal bleeding before surgery, which was hematemesis or melena. Six patients underwent gastroscopy to confirm the presence of esophageal gastric varices or portal hypertensive gastropathy, and one patient considered to have variceal bleeding at the site of a biliary-enteric anastomosis. Pre-operative enhanced CT and B-ultrasonography (BUS) confirmed the PVCT, with an unobstructed intrahepatic PV and SMV trunk without lesion in the hepatic outflow tract. Eight patients had a history of abdominal disease that might induce PVCT, including biliary-enteric anastomotic stenosis (1 case), pylephlebitis secondary to appendicitis (1 case), liver trauma surgery (1 case), liver transplantation (2 cases), ex situ hepatectomy (1 case), bowel obstruction (1 case), pancreatitis (1 case) (Table 1).

Three patients had a risk of thrombosis with decreased protein C activity or lower antithrombin III levels. Pre-operative or intra-operative biopsy confirmed that there was no liver cirrhosis or hepatic venous disease. All patients were confirmed to have MRB surgical indications and were eligible for surgery. Only 4 patients in Group A required the use of autologous right internal jugular veins, and the remaining 9 patients used allogeneic blood vessels. In Group A, 1 patient simultaneously underwent biliary-enteric anastomosis and cholangiolithotomy, and 1 patient simultaneously underwent cholecystostomy and splenic artery ligation. Of the 13 patients, 5 patients received end-to-end anastomosis of the bypass vessel with the confluence of SMV and SpV, and 8 patients received anastomosis of the bypass vessel with the SMV or SpV trunk. The ethics committee of Beijing Tsinghua Changgung Hospital approved the study, and written informed consent was obtained from all participants.

**Statistical analysis**

Pre- and postoperative data including bypass vascular flow, the diameter of the narrowest part of the blood vessel, opening times, and the incidence of vascular occlusion were collected and analyzed using SPSS ver. 20 (IBM Corporation, Armonk, NY, USA). Measurement data for skewed distributions are reported as medians with the ranges. The measurement data for normal distribution are presented as the mean ± SD and paired data analyzed using a paired t-test. P < 0.05 was considered to be a statistically significant difference.

**Operative approaches**

The iliac vein, obtained from a donation after cardiac death, or the autologous right internal jugular vein were selected as the bypass vessels. Great efforts were made to ensure that there were no residual tortuous or redundant blood vessels during the bypass procedure.

Group A (traditional MRB): Rex recess was treated as described in the literature (Fig. 1).

Ultrasoundography confirmed that there was a fluent blood flow in LPV and the hepatic parenchyma around the Rex recess was excised to expose the LPV. Sufficiently large incisions were made in the sagittal part of the PV to ensure fluent blood flow (at least 5 mm in diameter) and to avoid anastomotic stenosis. Anastomotic stoma selection at the distal end of the bypass vessel depended on whether it was possible to separate the stump of the PV where the SMV and SpV converged, and the vessel was severed at the stump of the PV. If it was not possible to separate the stump of the PV where the SMV and SpV converged, then the SMV trunk or SpV trunk was selected (if splenectomy was performed, only the SMV trunk could be selected), as close as possible to the confluence part. The sidewall of the SMV or SpV was blocked using a vascular blocking forceps, and end-to-side anastomosis of the bypass vessel with the SMV or SpV was performed.

Group B modified MRB (mMRB): Similarly, ultrasoundography confirmed that there was fluent blood flow in the LPV. The stump of the ligamentum teres hepatitis was excised if the ligamentum teres hepatitis was completely buried in the hepatic parenchyma and could not be directly separated.)
Table 1 Pre-operative characteristics

| Group        | Patient no | Age | Gender | Surgical treatments (anastomotic place and stent placement) | The smallest diameter (mm) | Suspicious causes, history, and risk factors for PVCT | Type of blood vessels |
|--------------|------------|-----|--------|-------------------------------------------------------------|-----------------------------|------------------------------------------------------|----------------------|
| A (Conventional) | 1          | 42  | Male   | MRB (sagittal part)                                         | 3 (change to 5 after recanalization) | Secondary, biliary-enteric anastomotic stenosis       | Autologous blood vessels |
|              | 2          | 42  | Female | MRB (sagittal part)                                         | 3.5                         | Original, unknown                                     | Autologous blood vessels |
|              | 3          | 36  | Male   | MRB (sagittal part)                                         | 4                           | Secondary, pyelonephritis secondary to appendicitis    | Autologous blood vessels |
|              | 4          | 19  | Male   | MRB (sagittal part)                                         | 2.5 (change to 5 after recanalization) | Secondary, liver trauma surgery                      | Allogeneic blood vessels |
|              | 5          | 54  | Male   | MRB (sagittal part)                                         | 6                           | Secondary, liver transplantation                      | Allogeneic blood vessels |
|              | 6          | 11  | Male   | MRB (sagittal part)                                         | 2 (change to 5 after recanalization) | Original, decreased protein C activity               | Allogeneic blood vessels |
|              | 7          | 31  | Male   | MRB (sagittal part)                                         | 5                           | Original, lower antithrombin III levels               | Autologous blood vessels |
|              | 8          | 36  | Female | MRB (sagittal part)                                         | 3                           | Original, lower antithrombin III levels               | Allogeneic blood vessels |
|              | 9          | 25  | Female | MRB (recanalized umbilical vein)                            | 0 (change to 5 after recanalization) | Secondary, ex situ hepatectomy                        | Allogeneic blood vessels |
| B (Novel)    | 10         | 62  | Female | MRB (UV recanalization and intra-operative stent implantation) | 5.5                         | Secondary, liver transplantation                      | Allogeneic blood vessels |
|              | 11         | 22  | Male   | MRB (UV recanalization and intra-operative stent implantation) | 6.5                         | Original, unknown                                    | Allogeneic blood vessels |
|              | 12         | 36  | Male   | MRB (UV recanalization and intra-operative stent implantation) | 6                           | Secondary, bowel obstruction                         | Allogeneic blood vessels |
|              | 13         | 31  | Male   | MRB (UV recanalization and intra-operative stent implantation) | 6                           | Secondary, pancreatitis                              | Allogeneic blood vessels |

Fig. 1 Traditional MRB surgery for treatment of the portal vein sagittal section. The blue arrows show the vascular anastomotic stoma of the sagittal section before (A) and after (B) anastomosis.
was separated and retained. The stump of the ligamentum teres near the root was transected, and then the small vascular openings in the ligament and a small amount of blood overflow were visible, which was determined to be an umbilical vein with incomplete atresia. Using a vascular dilator (sequentially using 12-18F) to dilate through these vascular openings in the ligament, they were opened up into the liver until the LPV, then blood outflow was observed and umbilical vein recanalization completed (Fig. 2A).

During the recanalization process, the septum structure could be reached through the junction between the ligamentum teres and the PV, which had a “sense” of resistance. The junction at this location was narrower than the vessels on both sides. End-to-end anastomosis of the bypass vessel with the recanalized umbilical vein was performed using a 5–0 prolene suture (Fig. 2B). Several vascular stents (peripheral self-expanding stent system, 6×8 mm, 6×10 mm) were implanted from the distal end of the bypass vessel in Group B patients under ultrasonography or angiography guidance (Fig. 2C). These stents covered the LPV-UV-anastomotic stoma-bypass vessel to ensure the patency of the vascular lumen (red arrows indicate the vascular stent). End-to-end anastomosis of the bypass vessel in which the stent is visible; the blue arrow indicates the SMV (Fig. 2D). The distal anastomosis of bypass in Group B was the same as in Group A. After the vascular anastomosis was completed, the bloodstream was opened to check for bleeding and whether vascular filling was more than satisfactory (Fig. 2E).

One patient received umbilical vein recanalization with the SMV through the ligamentum teres hepatitis but did not

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**Fig. 2** Intra-operative images of modified mMRB surgery. A UV recanalization. The white arrow shows the vascular dilator. B After the UV was recanalized, end-to-end anastomosis was performed with the bypass vessel. The yellow arrow indicates the anastomotic stoma. C Ultrasonography or radiography-guided stent implantation of the bypass vessel into the LPV. The white arrow indicates the bypass vessel, and the green arrow indicates the angiographic catheter. D Intra-operative angiography revealed that the UV and LPV were narrowed (yellow arrow in a and b improvement of the blood vessel diameter after stent implantations. c The successively implanted stent covers the LPV-UV-anastomotic stoma-bypass vessel to ensure the patency of the vascular lumen (red arrows indicate the vascular stent). E Intra-operative images of a the upper and b lower anastomotic stoma after the mMRB surgery was completed (the yellow arrows indicate the vascular anastomotic stoma; the white arrows indicate the bypass vessel; the blue arrow indicates the SMV).
have a stent implantation procedure and was included in group A.

The patient’s blood flow was checked by ultrasonography after surgery [11] (Fig. 3A). Pre- and postoperative images using enhanced CT revealed that the bypass vessels were unobstructed, the lumen diameter was appropriate, intrahepatic portal vein blood flow was patent, and that the pre-operative varicose right gastroepiploic vein diameter had become smaller (Fig. 3B).

All patients received anticoagulant therapy after surgery. The regimen was to intravenously infuse heparin within 2–3 days of surgery to maintain the activated partial

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**Fig. 3** Post interventional ultrasound and 3D images of livers in Group B before and after surgery. A Ultrasound showing the vascular stent and blood flow in the stents of all 4 patients in Group B. B Pre-operative a and postoperative b three-dimensional reconstruction of patients in Group B (the white arrows indicate the LPV, the red arrow indicates the PVCT in the hepatic hilar region, the blue arrows indicate SMV, the black arrow indicates the bypass vessel and its internal stent, and the green arrows indicate the right gastroepiploic vein)
thromboplastin time (APTT) between 50 and 70 s and then was switched to a preventive dose of low molecular weight heparin. After discharge, the patient took orally rivaroxaban 20 mg or aspirin 100 mg once a day. Anticoagulation therapy was generally recommended for 3–6 months, and patients with stent implantation and risk of thrombosis were given anticoagulation therapy for >1 year or even for their lifetimes.

**Results**

**Postoperative patency and outcomes of interventional or surgical treatments**

All patients obtained a satisfactory decompression effect after bypass surgery, and the intra-operative SMV pressure decreased from $36.77 \pm 4.48 \text{ cmH}_2\text{O} (29–44 \text{ cmH}_2\text{O})$ to $24 \pm 5.08 \text{ cmH}_2\text{O} (16–31 \text{ cmH}_2\text{O})$ ($P < 0.01$). The MRB opening time for patients using autologous blood vessels was 0–67 months (median 39 months), and the MRB opening time for patients used allogeneic blood vessels was 0–56 months (median 15 months) ($P = 0.389 > 0.05$) (Table 2).

Group A: The mean blood flow velocity of MRB patients in Group A was 25–115 cm/s (median 72 cm/s) at 1 month after MRB 0–161 cm/s (median 87 cm/s) 3 months after MRB and 0–180 cm/s (median 66 cm/s) 1 year after MRB, and the opening time of bypass was 0–67 months (median 6 months). In Group A, 6 of 9 MRB patients developed postoperative MRB occlusions, of whom 5 underwent surgery or interventional treatments for the thrombus or stenosis of the bypass vessels at 0–6 months (median 3 months) after surgery (Table 2).

By the end of the follow-up, 3 patients still had MRB occlusion (1 patient developed occlusion at 26 months after MRB and was not subsequently treated; 1 patient occluded again after thrombectomy and recanalization, without subsequent treatment; 1 patient was found to be unable to be recanalized during interventional treatment, and no other treatment was performed). The diameter of the bypass vessels after MRB surgery was 0–6 mm (median 3 mm), among which 6 patients had an MRB occlusion with <4-mm vessel diameter, but no embolism occurred in patients with a bypass vessel diameter ≥4 (Table 2).

Vessel diameters in 2 patients with vascular occlusions were 2 mm and 2.5 mm, while the re-examined diameters were 5 mm after interventional MRB therapy with recanalization and stent implantation. The bypass vessel remained unobstructed from the time of stent implantation to the end of follow-up. One patient was recanalized only by surgical thrombus extraction and reshaping the diameter of the vascular anastomotic stoma, without stent implantation, and occlusion occurred 15 months after the 2 operations (Table 2).

In addition, 1 patient in Group A who received umbilical vein recanalization with the SMV through the ligamentum teres hepatitis but did not have a stent implantation procedure needed thrombectomies and stent implantation after the MRB intervention during a second surgery 2 days after the first one because of bypass thrombosis and UV stenosis. The MRB remained unobstructed for 33 months from the time of followed stent implantation to the end of follow-up, with a vessel diameter of 5 mm and a blood flow rate of 42 cm/s (1 year after MRB) (Table 2).

Group B: A total of 9 stents were implanted in 4 patients, of which 3 were implanted in 1 patient and 2 implanted in each of the remaining 3 patients. All patients successfully received recanalization of the UV, and resistance could be detected at the junction of the UV and the sagittal part of PV, which is a narrow ring. All patients were able to successfully receive an implant stent in the LPV-UV through the distal end of the bypass vessel.

All bypass vessels remained open in patients in Group B, with satisfactory blood flow rates (45–100 cm/s, median 76.5 cm/s) 1 month after MRB, 28–80 cm/s (median 59 cm/s) 3 months after MRB, and 65–83 cm/s (median 66 cm/s) 1 year after MRB up to the endpoint (15–33 months, median 24 months). The diameter of the bypass vessels after MRB surgery was 5.5–6.5 mm (median 6 mm) (Table 2).

The rate of bypass closure in Group A vs Group B at 1 month, 3 months, and 1 year after MRB surgery was 22.2% vs 0%, 30.0% vs 0%, and 55.6% vs 0%, respectively.

**Adverse events**

Non-bypass vessel related Clavien-Dindo grade III or higher complications occurred in 2 patients. The patient in Group A who underwent biliary-enteric anastomosis, suffered from bile leakage and abdominal infection after surgery and were treated with laparotomy again. In Group B, 1 patient developed a jejunal fistula after surgery and was cured by re-operation, which was considered to be related to an intraoperative thermal injury; no complications occurred in the remaining 3 patients.
Discussion

Anatomical basis of surgical feasibility and stent implantation

After the left UV enters the liver from the umbilicus along the margin of the falciform ligament during the fetal period, it branches into two: one vein that extends directly into the Arantius tube and is connected to the inferior vena cava, and the other is connected to the LPV. After birth, the pressure of the UV decreases, and the vascular wall shrinks and gradually closes. There have been reports of MRB surgery with UV recanalization, mainly for underage patients [12, 13], but without the use of intra-operative stents.

The present study suggested that this type of end-to-end anastomosis was more convenient, and it was easier to achieve intravascular therapy, allowing a large-caliber anastomosis and a good portal blood flow volume. It should be pointed out that a high-pressure sodium heparin perfusion for the recanalized UV helped to maintain this access patency and thus the intrahepatic PV circulation. In clinical practice, we found that there was a “septum structure” in the transition from adult UV to PV, which is a natural narrowing ring. The patency of this narrow lumen must be ensured by intra-operative stenting; otherwise, vascular occlusion and thrombosis (Group A No. 9) will certainly occur, which may also be the main difference between adult and pediatric patients. After stent implantation, the head-end of the stent should ideally be positioned at the confluence of the left and right PV, covering the entire left PV-UV-bypass vessel. A non-covered stent was selected during the operation so that blood could flow into the P2, P3, and P4 branches of the PV sagittal part through the side hole of the stent, ensuring a good blood supply to the left liver.

Surgical advantages of umbilical vein recanalization

In classical MRB, a portion of the liver (from both segments III and IV) around the umbilical scissure has to be resected to create a route for the bypass and to avoid compression by the liver edges. Before anastomosis on the Rex recess, a Satinsky clamp was positioned behind the branches for segments II, III, and IV and a vertical incision made on the ventral aspect of the Rex recess at the margin with the umbilical remnant. Our surgical approach simplifies the anatomy of Rex recess, avoiding liver resection and left hepatic surface adhesiolysis, especially for patients with severe abdominal adhesions, left liver hyperplasia, or a Rex recess deeply buried in the liver (Fig. 4A). In cases where the UV was not patent, the sagittal part of the LPV could be used for a side-to-end anastomosis, according to the classical MRB procedure.

The necessity for a primary stent implantation

There are many reasons leading to thrombosis after MRB surgery, including the diameter of blood vessels, whether there is a hypercoagulability state, the pressure gradient difference between the two sides of the bypass vessels, and the condition of the bypass vessels. Previous reports have suggested that autologous vasculature should be preferred over allogeneic and artificial blood vessels [14–16]. Our results suggested that the opening time of allogeneic blood vessels in Group A patients was shorter than for autologous blood vessels, a finding consistent with previously published literature [6]. However, this comparison did not reach statistical significance, we believe mainly due to the small sample size and to brief follow-up times. In addition to being squeezed by surrounding tissues, surgery may also stimulate inflammation and fibrous tissue hyperplasia around the bypass vessels, or an immune response to allogeneic blood vessels, resulting in postoperative bypass vascular stenosis and anastomotic stenosis, thereby producing vascular occlusion. The main aim of the primary stent implantation approach is to solve the problem of thrombus formation or vascular occlusion in bypass vessels caused by vascular diameter stenosis. For example, in Group A MRB patients, the anastomotic diameter at Rex was confirmed to be greater than 5 mm during surgery, and 6 of them narrowed to < 4 mm in diameter after surgery, resulting in occlusion. Two of the patients underwent interventional stent implantation after vascular occlusion, which expanded the blood vessel diameter to > 5 mm, and no embolism occurred again (Fig. 4B4B). Therefore, it is clear that stent implantation helped to ensure the patency of blood vessels and avoid the existence of narrow regions.

Intra-operative primary stent implantation can be achieved under the guidance of ultrasonography or angiography, which permits superior hand control and vascular access under direct vision and also reduces the risk of postoperative secondary interventional therapy as a result of liver or spleen puncture. Our mode of operation is similar to the p4 stump approach for intra-operative portal vein stenting in pediatric living donor liver transplantation [17]. Ultrasonography should be performed every day within 2 weeks of surgery to ensure that blood flow is fluent. In addition, patients undergoing stent implantation or patients at risk of thrombosis (including those that have had a previous thrombosis or a flow rate in bypass vessels of < 20 cm/s) may require lifetime anticoagulant therapy to prevent stent thrombosis. Our anticoagulation regimen is to infuse heparin within 3 days of surgery, to maintain APTT between 50 and 70 s, and to switch to a therapeutic dose of low molecular weight heparin after 3 days, followed by a change to oral
| Group | Patient no | The time of occlusion after surgery (month) | MRB opening time, from postoperative to endpoint (month) | Type of recanalization after MRB (surgery or interventional therapy) | SMV pressure, before surgery (cmH₂O) | SMV pressure, after surgery (cmH₂O) | Blood flow velocity, 1 month after surgery (cm/s) | Blood flow velocity, 3 months after surgery (cm/s) | Blood flow velocity, 1 year after surgery (cm/s) | Clavien-Dindo grade |
|-------|------------|---------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------|--------------------------------------|--------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------|
| A     | 1          | 0 (occlusion occurred immediately after surgery, and recanalization was performed. Occlusion occurred again 15 months after surgery) | 0                                                      | Thrombectomy                                                   | 42                                   | 29                                   | 40 (after recanalization)                | 15                                       | 11                                        | IIIb             |
|       | 2          | 26 (occlusion occurred 26 months after surgery, and no recanalization was performed) | 26                                                     | -                                                             | 31                                   | 16                                   | 25                                       | 23                                       | 40                                        |
|       | 3          | -                                                            | 67                                                     | -                                                             | 44                                   | 28                                   | 72                                       | 136                                      | 180                                      |
|       | 4          | 5 (occlusion occurred 5 months after surgery, and recanalization was performed. The MRB remained unobstructed 52 months after recanalization) | 5                                                      | Interventional therapy                                        | 39                                   | 30                                   | 78                                       | 95                                       | 87 (after recanalization)               | IIIa             |
|       | 5          | -                                                            | 56                                                     | -                                                             | 41                                   | 31                                   | 88                                       | 161                                      | 66                                        |
|       | 6          | 6 (occlusion occurred 6 months after surgery, and recanalization was performed. Re-occlusion occurred 13 months after recanalization) | 6                                                      | Thrombectomy + interventional therapy                        | 35                                   | 26                                   | 115                                      | 110                                      | 98 (after recanalization)               | IIIb             |
|       | 7          | -                                                            | 52                                                     | -                                                             | 38                                   | 24                                   | 80                                       | 76                                       | 84                                        |
|       | 8          | 3 (occlusion occurred 3 months after surgery, and recanalization was performed but not succeeded) | 3                                                      | Interventional therapy                                        | 29                                   | 18                                   | 72                                       | 0 (occlusion occurred)                  | 0 (occlusion occurred)                 | IIIa             |
|       | 9          | 0 (occlusion occurred immediately after the surgery, and recanalization was performed. The MRB remained unobstructed 33 months after recanalization) | 0                                                      | Thrombectomy + interventional therapy                        | 37                                   | 21                                   | 61 (after recanalization)                | 87                                       | 42                                        | IIIb             |
| B     | 10         | -                                                            | 33                                                     | -                                                             | 36                                   | 25                                   | 100                                      | 80                                       | 83                                        | IIIb             |
|       | 11         | -                                                            | 23                                                     | -                                                             | 33                                   | 18                                   | 53                                       | 38                                       | 65                                        |
|       | 12         | -                                                            | 26                                                     | -                                                             | 40                                   | 27                                   | 100                                      | 80                                       | 66                                        |
|       | 13         | -                                                            | 15                                                     | -                                                             | 33                                   | 19                                   | 45                                       | 28                                       | 34                                        |
rivaroxaban 20 mg qd or aspirin 100 mg qd about 2 weeks after surgery. Oral warfarin can also be used to maintain international normalized ratio at 2–3, but at present, there is no uniform anticoagulation standard. The small sample size of our study may lead to bias; therefore, a long-term follow-up with a larger cohort of patients is still needed to determine whether this surgical approach helps maintain satisfactory long-term blood flow in bypass vessels.

**Conclusions**

UV can be used as a conduit of MRB in adult patients, and an intra-operative stent must be implanted. Compared with traditional MRB surgery, this approach is relatively simple and ensures satisfactory bloodstream access, which will reduce the risk of intravascular thrombosis and bypass vessel occlusion after surgery.

**Authors’ contributions** Study conception and design: RT, LY, GW, AL, YZ, and QL. Acquisition of data: RT, GW, AL, YZ, and YL. Analysis and interpretation of data: RT, LY, XT, and HH. Drafting of manuscript: All authors. Critical revision of manuscript: All authors.

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**Data availability** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Code availability** Not applicable.

**Declarations**

**Ethics approval** The ethics committee of Beijing Tsinghua Changgung Hospital (no. 20311–0-01) approved the study and certified that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

**Consent to participate** Informed consent was obtained from all individual participants included in the study.

**Consent for publication** Not applicable.

**Conflict of interest** The authors declare no competing interests.

**References**

1. Harmanci O, Bayraktar Y (2007) Portal hypertension due to portal venous thrombosis: etiology, clinical outcomes. World J Gastroenterol 13(18):2535–2540. https://doi.org/10.3748/wjg.v13.i18.2535

2. Nasim M, Majid B, Tahir F, Majid Z, Irfan I (2019) Cavernous transformation of portal vein in the setting of protein C and antithrombin III deficiency. Cureus 11(9):e5779–e5779. https://doi.org/10.7759/cureus.5779
3. Zhang JS, Li L, Cheng W (2016) A new procedure for the treatment of extrahepatic portal hypertension in children: portal cavernoma-Rex shunt with interposition of grafted portal vessel. J Am Coll Surg 222(6):c71-76. https://doi.org/10.1016/j.jamcollsurg.2016.03.020

4. Ha TY, Kim KM, Ko GY, Oh SH, Kwon TW, Cho YP, Lee SG (2015) Variant meso-Rex bypass with transposition of abdominal autogenous vein for the management of idiopathic extrahepatic portal vein obstruction: a retrospective observational study. BMC Surg 15:116. https://doi.org/10.1186/s12893-015-0101-6

5. Wei Z, Rui SG, Yuan Z, Guo LD, Qian L, Wei LS (2014) Partial splenectomy and use of splenic vein as an autograft for meso-Rex bypass: a clinical observational study. Med Sci Monit 20:2235–2242. https://doi.org/10.12659/MSM.892482

6. de Ville de Goyet J, Lo Zupone C, Grimaldi C, D’Ambrosio G, Candusso M, Torre G, Monti L (2013) Meso-Rex bypass as an alternative technique for portal vein reconstruction at or after liver transplantation in children: review and perspectives. Pediatr Transplant 17(1):19–26. https://doi.org/10.1111/j.1399-3046.2012.01784.x

7. di Francesco F, Grimaldi C, de Ville de Goyet J (2014) Meso-Rex bypass—a procedure to cure prehepatic portal hypertension: the insight and the inside. J Am Coll Surg 218(2):e23-36. https://doi.org/10.1016/j.jamcollsurg.2013.10.024

8. Bhat R, Lautz TB, Superina RA, Liem R (2013) Perioperative strategies and thrombophilia in children with extrahepatic portal vein obstruction undergoing the meso-Rex bypass. J Gastrointest Surg 17(5):949–955. https://doi.org/10.1007/s11605-013-2155-z

9. Area C, Kirsch D, Gohwarji L (2017) Clinical images: interventional management of pediatric Rex shunt stenosis. Ochsner J 17(1):6–8

10. Zhang JS, Li L, Cheng W (2018) Surgical treatment for rebleeding caused by bypass failure after Rex shunt: re-Rex shunt or Warren shunt? Pediatr Surg Int 34(5):521–527. https://doi.org/10.1007/s00383-018-4246-0

11. Ruan Z, Wu M, Shao C, Zhang Y, Zhang C, Zhang F, Zhao B (2020) Effects of Rex-bypass shunt on the cavernous transformation of the portal vein in children: evaluation by the color Doppler ultrasonography. Insights Imaging 11(1):4. https://doi.org/10.1186/s13244-019-0815-6

12. Facciuto ME, Rodriguez-Davalos MI, Singh MK, Rocca JP, Rochon C, Chen W, Katta US, Sheiner PA (2009) Recanalized umbilical vein conduit for meso-Rex bypass in extrahepatic portal vein obstruction. Surgery 145(4):406–410. https://doi.org/10.1016/j.surg.2008.12.004

13. de Ville de Goyet J, Alberti D, Clapuyt P, Falchetti D, Rigamonti V, Bax NM, Otte JB, Sokal EM (1998) Direct bypassing of extrahepatic portal venous obstruction in children: a new technique for combined hepatic portal revascularization and treatment of extrahepatic portal hypertension. J Pediatr Surg 33(4):597–601. https://doi.org/10.1016/s0022-3468(98)90324-4

14. Ketenciler S, Boyacıoğlu K, Akdemir İ, Komürçu G, Polat A (2018) Autologous saphenous vein panel graft for vascular reconstruction. Ann Vasc Surg 53:117–122. https://doi.org/10.1016/j.avs.2018.05.037

15. Pashneh-Tala S, MacNeil S, Claeyssens F (2016) The tissue-engineered vascular graft-past, present, and future. Tissue Eng Part B Rev 22(1):68–100. https://doi.org/10.1089/ten.teb.2015.0100

16. Klinkert P, Post PN, Breslau PJ, van Bockel JH (2004) Saphenous vein versus PTFE for above-knee femoropopliteal bypass. A review of the literature. Eur J Vasc Endovasc Surg 27(4):357–362. https://doi.org/10.1016/j.ejvs.2003.12.027

17. Chen CL, Cheng YF, Huang Y, Lin TL, Chan YC, Ou HY, Yong CC, Wang SH, Lin CC (2018) P4 stump approach for intraoperative portal vein stenting in pediatric living donor liver transplantation: an innovative technique for a challenging problem. Ann Surg 267(3):e42–e44. https://doi.org/10.1097/SLA.0000000000002333

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