The Role of Color Doppler Ultrasound in Living Donor Liver Transplantation

Tung-Liang Huang*

Color Doppler ultrasound (CDUS) is performed to ensure perfect vascular reconstruction after hepatic reperfusion. For the immediate assessment of general condition and early detection of vascular complications, CDUS is becoming essential and is the modality of choice to evaluate hepatic hemodynamics. Thus, CDUS is an important modality, which is widely used in all types of liver transplantation, and is performed in the preoperative, intraoperative and postoperative periods for routine evaluation of vasculature. Timely recognition of any threat of vascular complications improves the success of living donor liver transplantation. This article will review the current applications of CDUS in living donor liver transplantation.

KEY WORDS — color Doppler ultrasound, living donor liver transplantation

Introduction

Liver transplantation (LT) is now a well accepted therapy for end-stage liver disease. Due to a shortage of cadaveric donors, advances in modern hepatectomy techniques have resulted in the success of living donor liver transplantation (LDLT) as a routine procedure for end-stage liver disease. LDLT has also become the major source of livers for transplantation, especially in Asia. However, the threat of vascular complications is still a problem and the major cause of graft failure. If a liver graft fails, it is almost impossible for a patient to receive a second graft in Taiwan; thus, it is necessary to eliminate the possibility of graft failure. Many imaging modalities and interventional procedures are involved in the diagnosis and management of these problems.

Color Doppler ultrasound (CDUS) is performed to ensure perfect vascular reconstruction after hepatic reperfusion. For the immediate assessment of general condition and early detection of vascular complications, CDUS is becoming essential and is the modality of choice to evaluate hepatic hemodynamics. Thus, CDUS is an important modality, which is widely used in all types of LT and is performed in the preoperative, intraoperative and postoperative periods for routine evaluation of vasculature. Timely recognition of any threat of vascular complications improves the success of LDLT [1–4]. This article will review the current applications of CDUS in LDLT.
The Principles and Methods for Instrumental Hepatic Vascular Measurements

The CDUS instruments used are Acuson Aspen and Sequoia scanners (Acuson, Mountain View, CA, USA; the machines used in most transplant centers and published papers), which have a phased array of 3.5, 4.0, 5.0 or 7.0 MHz scanners in the imaging and Doppler mode, respectively. Measurements of blood flow by Doppler ultrasound include qualitative evaluations such as determination of the presence of flow, direction of color signal flow, and any abnormal flow indicating vascular insufficiency or stenosis. The quantitative evaluations performed include the measurement of flow velocity, flow volume and calculation of flow index. The width of the sample volume for pulsed Doppler flowmetry, which ranges from 1 to 5 mm, is dependent on the diameter of the detected vessels. The pulse repetition frequency which ranges from 3.0 to 9.0 kHz and is selected to obtain adequate Doppler spectral waveforms of the targeted blood vessels without aliasing. CDUS examinations are performed for hemodynamic evaluation of the portal vein (PV), hepatic vein (HV) and hepatic artery (HA) in the pretransplantation, intraoperative and postoperative periods, respectively.

Pretransplantation study

In the pretransplantation study of the native liver of the recipient, the measurement of PV flow is obtained at the extrahepatic portion of the main PV near the bifurcation. The size and flow direction of the PV are recorded. Any abnormal intraluminal portal thrombus or flow occlusion should be ruled out. The flow of the HA is recorded along with waveform, peak systolic velocity (PSV), resistance index (RI [RI = PSV - EDV/PSV, where EDV = end-diastolic velocity]) and pulsatility index (PI [PI = PSV - EDV/Vm, where Vm = mean velocity]), obtained at the hepatic hilum for quantitative evaluation. The absence of HA flow in the liver may be related to arterial occlusion (Fig. 1).

Intraoperative study

In the intraoperative study of the liver graft, the measurements of HV, PV and HA are performed both just after graft reperfusion and abdomen closure. All the PV measurements are obtained at the intrahepatic and extrahepatic portion over and along the anastomosis. The size, flow direction and velocity of the PV are recorded. The angle-corrected flow velocity and cross-sectional area of the PV at the same site should also be recorded. The sample volume size for the Doppler ultrasound mode is set at 3–5 mm, about half the diameter of the measured PV. The PV mean velocity should be corrected by the angle between the long axis of the PV and the Doppler beam of less than 60°. The portal flow volume per body weight is also calculated by the PV sectional area and mean velocity using the formula: portal vein flow volume (PVFV) = A × Vm, where A = sectional area (Fig. 2). The measurements of the HA flow including waveform, PSV, RI and PI are performed at the intrahepatic portion of the liver graft. The PSV of the HA is detected with suitable gate and angle correction along the long axis of the color-coded HA. The angle between the long axis of the color-coded HA and the Doppler beam should be less than 60°. The Doppler sample
volume is set at 1–2 mm and the waveforms are made on the lowest possible frequency shift range without aliasing. The flow measurements of the HVs are performed at each anastomotic vein at the intrahepatic portion about 1–2 cm from the inferior vena cava. The detected velocities are taken at peak waveform and angle correction is done under less than 60°. The waveform patterns of the HVs are classified as monophasic, biphasic or triphasic, reflecting the cardiac oscillation from the pressure change of the right atrium (Fig. 3).

**Postoperative study**

In the postoperative study, CDUS examinations are performed once a day during the first week after surgery. The protocol for both qualitative and quantitative hemodynamic evaluations follow the previous general principles for PV, HV and HA, respectively. The first postoperative CDUS examination is best performed within 12 hours after surgery. After 7 postoperative days, the schedule for CDUS is once per week before discharge or based on need according to clinical condition.

**Fig. 2.** Standard model of scanning by color Doppler ultrasound showed portal vein flow and measurement of parameters with angle correction and scale without aliasing. For this case, the formula and calculations were as follows: portal vein flow volume (PVFV) = mean of flow velocity (Vm) × cross-section area (A) = 39 × 60 × π × (0.78/2)^2 = 1,118 mL/min; further calculation of PVFV in per 100 g graft weight is 172 mL/min/100 g.

**Fig. 3.** Standard model of scanning by color Doppler ultrasound showed hepatic vein flow and measurement of parameters with angle correction and scale without aliasing. For these cases, the waveform analysis and calculations were as follows: there are normal triphasic waveform and biphasic waveform in the case of (A) and (B), the peak of flow velocity (Vp) are 59 and 61 cm/s, respectively; otherwise, there is an abnormal monophasic waveform in the case of (C) and relatively low Vp.
The CDUS Study for Pretransplant Recipients on the Waiting List

Since the initiation of LDLT in Kaohsiung in 1994, we have evaluated many infants and young children with biliary atresia awaiting LT, and have found a high incidence of vascular anomalies in these patients. The incidence of associated vascular anomalies was found to be up to 42% (16/38 cases). These vascular anomalies included: absence or hypoplasia of the inferior vena cava \((n=3)\), congenital absence or hypoplasia of the PV \((n=8)\), and anomalous origin of the HA \((n=6)\) [2,3,5].

In the preoperative study, we also found a group of pediatric recipients with high HA RI (some with an RI > 1.0) and frequent admissions because of fever and sepsis. According to the survival analysis for all relevant risk factors, high HA RI (> 1.0) and low portal flow velocity (< 10 cm/s) had definite significance for mortality [6] (Fig. 4). These cases could no longer wait and required transplantation for life-saving reasons. For the preoperative evaluation of PV quality, a smooth portal wall and patent flow are essential. In our research report of a group with portal insults, portal occlusion or absence is a contraindication to LDLT, and low portal flow less than 7 cm/s and small portal size less than 4 mm are risk factors for intraoperative portal thrombosis [7]. With advances in surgical techniques, some cases of intraportal partial thrombosis have been overcome using venous grafts, and successful LDLT has been achieved in recent years by some centers. PV thrombosis is not a contraindication to LDLT, but the limit of thrombosis must not be

Fig. 4. For this case of a young child on the waiting list for liver transplantation, the HA impedance was detected with an resistance index of 1.20 (exceeding 1.0). This case has a high risk of mortality, and an early transplantation is a priority to save this patient’s life.

Fig. 5. These cases were evaluated in a pretransplant study and showed abnormal portal flow by color Doppler ultrasound: (A) the first case had portal vein (PV) occlusion with obscured PV tract and no portal flow signal; (B) the second had a small PV tract and slow low inflow (3 cm/s); (C) the third had reverse hepatofugal portal flow and pulsatile waveform due to an arteriportal shunt. These abnormal portal flows are significant and may be a contraindication to living donor liver transplantation or are a risk for post-transplant portal thrombosis.
beyond the main PV [8] (Fig. 5). All these predisposing vascular anomalies may be significant in the decision to transplant and are well detected by CDUS. Therefore, in deciding on the priority of patients waiting for early transplantation, CDUS plays a really important role in pretransplant assessment.

The Major Vascular Complications Detected by Intraoperative CDUS

**HA thrombosis and insufficiency**

HA thrombosis (HAT) is the most serious vascular complication in LT and results in hepatic necrosis, dysfunction and failure. The incidence of HAT in LT varies from 7.4–13% and is higher in adult LDLT [9]. The advancement of HA anastomosis using microsurgical techniques has improved the success rate of HA reconstruction. The diagnosis of HAT by CDUS just after reperfusion of the graft is reliable. The diagnostic criterion of HAT is the absence of Doppler signals, and in this situation, redo of HA anastomosis or thrombectomy for resuscitation must be undertaken immediately. If an abnormal flow pattern with dampened systolic peak and slow peak velocity (<30 cm/s) occurs, HA angulation, strangulation or spasm is usually the cause of HA insufficiency [4]. Rapid thrombosis formation in these cases is possible. CDUS can help to assess and confirm the optimal flow change after the problem is resolved. The peak systolic Doppler velocity (PSV) and waveform distal to the HA stenosis are also dampened, the PI and RI of the HA also fall owing to poststenotic reactive vasodilatation and distal impedance [10,11]. Under this condition, a low HA PSV due to a proportional increase in end-diastolic flow velocity is observed (Fig. 6). If the parameters of HA flow detected are distal to the anastomosis,

![Image](image_url)

**Fig. 6.** This case was evaluated during intraoperative color Doppler ultrasound (CDUS) after vascular reperfusion. (A) A dampened hepatic artery (HA) peak wave, such as tardus-parvus waveform due to partial thrombosis, was found. (B) Reopen for thrombectomy was done with a slight improvement in flow, but optimal flow was not noted. (C, D) Thus, redo of HA anastomosis was done and normal HA flow was regained as noted on CDUS check-up.
any dampened flow waveform and velocity will indicate the presence of anastomotic stenotic change in the proximal HA [12]. Intraoperative CDUS is easy to perform and provides the opportunity for immediate treatment of such inadequate arterial reconstructions. CDUS also plays an important role in reducing the incidence of HAT following LDLT [13,14].

**PV thrombosis, insufficiency and hyperperfusion**

If there are no Doppler flow signals in the reconstructed PV, thrombosis of the PV is highly suspected. However, poor PV flow signals with CDUS can be caused by acute angulation of the sound scanning beam to the axis of the portal tract (> 60°) or the obliteration of extrahepatic PV with intervening adipose tissue or bowel gas after surgery [10,11]. Thus, we should carefully exclude PV thrombosis by CDUS. Immediate thrombectomy is the gold standard for treatment of PV thrombosis. Inadequate low PV inflow (mean velocity < 12 cm/s) as PV insufficiency is usually detected in pediatric recipients owing to persistent large portosystemic collaterals such as the coronary vein, splenorenal shunt and gastrorenal shunt, sometimes owing to HV outflow obstruction or low cardiac output (Fig. 7). An increase in PV inflow can be achieved by ligation of portosystemic collaterals, relief of HV outflow obstruction or redo of PV anastomosis [13,15].

On the contrary, PV hyperperfusion may occur with extremely high PVFV above 250 mL/min/100 g in adult LDLT recipients. These patients will develop post-transplant hepatic dysfunction such as small-for-size syndrome, which is often found among those with a relatively small-for-size graft (graft-to-recipient weight ratio < 0.8) (Fig. 8). Portal hyperperfusion in small-for-size graft is thought to be the main cause of small-for-size syndrome by portal hypertension and damage to sinusoids and hepatocytes [16,17]. To overcome this problem, several therapeutic options have also been reported, such as surgical modulation of splenic arterial ligation or splenectomy to release portal hyperperfusion and liver tissue congestion [18–20] (Fig. 8). For detection of this disorder, CDUS is the most important modality for monitoring portal hemodynamics.

**HV outflow obstruction, HV thrombosis, HV stenosis**

Normal flow velocity and waveforms of HV should be more than 12 cm/s at the peak of biphasic or triphasic waveforms, which reflect the patency of hepatic outflow. Hepatic outflow obstruction after reperfusion will result in a hard consistency and dark discoloration of the graft noted by the surgeon during the operation. CDUS examination is used immediately for evaluation. The characteristic CDUS findings are: (1) mild dilatation of the HVs; (2) flat or monophasic HV flow waveform; (3) slow HV
peak velocity (<10 cm/s); and (4) extremely low PV flow velocity (<14 cm/s) [9,21]. Intrahepatic venous thrombus is usually observed in HV thrombosis and immediate thrombectomy is needed. During transplant surgery, torsion of the graft was described by Broelsch et al [22]. In our experience, right rotation of the graft in the wide abdominal space may result in outflow stenosis and a flat HV flow waveform (Fig. 9). We can prevent such outflow obstruction by fixing and stabilizing the graft in the optimal

Fig. 8. (A) This case of low graft-to-recipient weight ratio of 0.8 such as small-for-size graft, and extremely high portal vein flow volume (PVFV) up to 682 mL/min/100 g was detected by color Doppler ultrasound just after hepatic flow reperfusion. A high possibility of post-transplant dysfunction or graft failure exists in this case. (B) Immediate ligation of the splenic artery was carried out for modulation of portal hyperperfusion, and the PVFV was dramatically reduced to 233 mL/min/100 g, which was within normal limits. The postoperative course of this patient was uneventful.

Fig. 9. Case of a young child with right rotation of the graft in the wide abdomen during operation. (A) Hepatic vein (HV) outflow was impeded with a flat waveform and low peak velocity detected by intraoperative color Doppler ultrasound (CDUS). (B, C) For improvement of HV outflow obstruction, left-side fixation for a stable graft position and posthepatic balloon interposition to correct HV angulation were carried out until optimal HV flow was regained under CDUS guidance.
position under the guidance of intraoperative CDUS, until a normal biphasic HV waveform is obtained [1,11].

The Postoperative Vascular Complications Detected by CDUS

Postoperative HAT
Postoperative HAT usually occurs in the first postoperative day but can occur up to 1 week after surgery. We perform routine CDUS examinations on the first postoperative day, especially within 12 hours of surgery and in patients with high risk factors or with poor arterial quality. HAT is present in Doppler findings when absent arterial signals are found in the whole graft scan or when only dampened slow HA flow is noted. Further imaging with CT angiography is suggested for confirmation. HAT is usually successfully treated by thrombectomy or redo of anastomosis or jump graft following early diagnosis [23–25].

Postoperative PV thrombosis or PV stenosis
Postoperative PV thrombosis may also occur in the early postoperative period. CDUS shows slow or absent portal flow or direct visualization of thrombus. Sometimes, hepatofugal PV flow is noted and
may be associated with HV outflow obstruction [10,12,26]. Surgical thrombectomy, redo of anastomosis or infusion of a thrombolytic agent is used in the management of this disorder. Postoperative PV stenosis may develop and cause hepatic dysfunction with intractable ascites. CDUS examination shows marked turbulent flow or slow flow and extremely high-flow velocity (may be up to 200 cm/s) detected at the narrowed anastomosis. Further management with percutaneous transhepatic portal angioplasty with balloon dilatation or Wallstent interposition is suggested [15,27] (Fig. 10).

**Postoperative HV thrombosis or HV stenosis**

HV outflow obstruction may also develop after transplantation, the obstruction usually occurs at the anastomotic site and is mainly caused by chronic fibrosis at the stenotic site and hypertrophy of the graft [28,29]. CDUS detection shows a flat flow waveform and slow HV flow velocity (<10 cm/s); hepatofugal PV flow may occur in severe obstruction. Therapeutic procedures of angioplasty with balloon dilatation or Wallstent interposition are suggested for this disorder [30] (Fig. 11). CDUS is used to study both HV outflow obstruction and postoperative PV stenosis.

**Fig. 11.** A case of persistent intractable massive ascites (>2,000 mL/day) at postoperative color Doppler ultrasound examination. (A) Low hepatic vein (HV) peak velocity (Vp) with a flat waveform favored hepatic vein stenosis. (B, C) After percutaneous transluminal venoplasty with balloon dilatation and insertion of a Wallstent, (D) the HV waveform improved to a normal multiphasic pattern and Vp increased to 72 cm/s. Following this treatment, the ascites dramatically subsided.
before and after angioplasty or stenting for effective treatment with successful regain of normal HV outflow [31,32].

Conclusion

CDUS has wide use in LT and is the modality of choice in the evaluation of hepatic graft hemodynamics and the diagnosis of vascular complications. This modality has a very important role in preoperative, intraoperative and postoperative evaluations for the immediate assessment of general condition and early detection of complications. Timely recognition of any complications could improve the success of LT.

Chang Gung Memorial Hospital was the first center to perform LT in Taiwan and carried out a successful case of orthotopic liver transplantation in 1984, and was the first to start a program of LT. Due to the scarcity of source- and size-matched graft donors for infants and young children, we were the first to initiate cadaveric split-liver transplantation and LDLT, respectively. CDUS is now performed routinely for the evaluation of hepatic hemodynamics. Although high rates of vascular complications resulting in graft failure are still reported by many centers worldwide, our center has had good results.

References