

Technical progress in living donor liver transplantation for adults

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Background

Liver transplantation from a living donor (LDLT) was introduced during the 1990s to overcome the shortage of donor organs, particularly among children and in those countries in which cadaveric grafts were seldom available. In Japan alone, some 1700 LDLTs were performed in the first 12 years with a 5-year survival rate of 70% in adults and an even higher rate (82%) in children. The major limitation to successful LDLT is inadequate graft size, which usually necessitates the use of the whole right liver unless (1) the caudate lobe is included in a left liver graft, (2) only the right lateral sector is employed (segments VI and VII) or (3) left livers from two donors are implanted into one recipient.

Discussion

From a technical standpoint, the main problem with the various types of LDLT has been the venous reconstruction in

the recipient. For the left-sided graft, the hepatic vein of the caudate lobe should be re-anastomosed to prevent congestion of this segment. For the right-sided graft, there has been uncertainty about the need to reconstruct the middle hepatic vein (MHV). Implantation is clearly simpler without this additional step, but there is a risk of dysfunction and sepsis in the right paramedian sector. Venous congestion in this sector can be observed during operation, both visually after clamping the MHV and by ultrasonographic assessment of the direction of blood flow in the portal vein. These techniques can be used to determine which patients require bench reconstruction of MHV tributaries or indeed of the inferior right hepatic vein. These manoeuvres should improve graft function and survival.

Keywords

middle hepatic vein, congestion, reconstruction

Introduction

Strong and co-workers [1] reported the first successful liver transplantation from a living donor (LDLT) in 1990. LDLT is mainly undertaken in an attempt to alleviate the shortage of donor organs and to decrease deaths among children awaiting transplants [2]. After the first successful adult LDLT case reported by Hashikura and colleagues in 1993 [3], however, the number of adult patients has increased rapidly.

In Western countries, the shortage of grafts for adults is the main problem as regards liver transplantation [4]. More than 30 transplantation programmes have performed more than 400 LDLTs for adult patients in the USA. In Asia, where cadaveric liver transplantation is seldom performed, LDLT remains the only way to save the lives of patients with end-stage liver disease. According to the Japanese Society for Liver Transplantation, 1718 LDLT procedures were performed at 43 institutions in Japan from 1989 to November 2001. The 5-year survival rates were 81.5% in children and

69.7% in adults. The outcome in adults was significantly worse than that in children ($p < 0.0001$), which indicates that there are some unsolved problems in adult LDLT. This report describes recent technical advances in LDLT for adult patients.

Partial liver grafts: left or right?

The major limitation for LDLT for adults is the adequacy of the graft size. In initial LDLT, only a left liver graft was used [5]. Kiuchi and colleagues [6] reported that the graft, estimated to be 28% of the recipient's standard liver volume [7], was successfully transplanted in a patient with primary biliary cirrhosis. Lo and associates [8] reported that a graft estimated to be 25% of the recipient standard liver volume was transplanted in a patient with fulminant hepatic failure. However, some transplant surgeons suggested that the unsatisfactory results in adults might be due to undersized grafts, which might not meet the metabolic demands of the patient [9]. Accordingly, recent reports indicate that left liver

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grafts for adult patients have now been almost abandoned and right liver grafts are almost always used [10],

Clearly, a right liver graft can help to alleviate the problem of graft size disparity in adult-to-adult LDLT. We believe that routine use of a right graft cannot be justified, however, because right hemi-hepatectomy is not a sufficiently safe form of donor hepatectomy. The safety of right hepatectomy varies, depending mainly on the volume of the left liver. We do not perform right hepatectomy if the volume of the left liver is estimated to be <30% of the whole liver.

The harvested graft should be down-sized according to the pre-transplant condition [8] and the disease of the recipient [11]. A left liver with a caudate lobe graft [12] can provide an alternative to right liver graft. The caudate lobe corresponds to only 3-4% of the whole liver volume. In conjunction with a left liver graft, however, the caudate lobe provides an 8-12% gain in weight. The rate of postoperative cholestasis in patients decreases significantly when using the left liver with the caudate lobe.

Vein reconstruction in left side graft

Takayama and associates [13] emphasised the importance of short hepatic vein reconstruction. The hepatic vein of the caudate lobe can be resected on the cuff of the vena cava, which resembles a Carrel's patch. In the recipient operation, reconstruction of the caudate hepatic vein is performed first. The trunk of the left hepatic vein (LHV) and middle hepatic vein (MHV) of the recipient and the graft are then anastomosed. Recently, a new technique [14] was described by which the left liver plus caudate lobe was implanted with complete reconstruction of a short hepatic vein. This technique is applicable when the orifice of the short hepatic vein is located near those of the LHV and MHV.

According to the cast study by Couinaud [15], 69% (66/96) of caudate lobes have a single vein and 20% have two. Most of the veins (91%, 115/126) enter directly into the vena cava. That study indicated that one or two veins of the caudate lobe should be reconstructed to prevent venous congestion of the caudate lobe. To estimate the success of reconstruction of the caudate hepatic vein, computed tomography (CT) was performed 1 month after the operation. Regeneration of the left liver and the caudate lobe was comparable to that of the left liver [16].

Vein reconstruction in right side graft

A right liver graft without the MHV trunk is now commonly used. In the initial reports of LDLT using this type of right liver graft, the MHV tributaries were not reconstructed [17-19]. Lee and colleagues [20] emphasised the necessity of MHV reconstruction in this type of graft. They noted that the graft could develop severe congestion of the right paramedian sector because hepatic venous outflow of the right paramedian sector drains mostly into the MHV. Such congestion can cause severe graft dysfunction and septic complications.

MHV drainage into the recipient's venous system can be reconstructed by means of vein grafts. This technique provides a functioning liver mass comparable to an extended right liver graft. Some transplant teams now seem to recognise the value of reconstruction of the MHV tributaries. Cattral and associates [21] reported a case of reconstruction using the recipient's left portal branch. Ghobrial and colleagues [22] reported a venous variant with a small right hepatic vein and large MHV branch and proposed that MHV reconstruction should be performed in such cases. Lee and colleagues [23] recently reported a series of 42 adult recipients. All sizeable (>5mm in diameter) MHV tributaries were preserved during donor hepatectomy and were reconstructed with the recipient's autogenous interposition vein grafts at the surgical bench. Serial Doppler ultrasonography revealed a patent interposition vein graft in 38 of 42 recipients until 30 days post-transplant. In these 38 recipients, no evidence of congestion in the right paramedian sector was recognised on enhanced CT, while the procedure provided enough functioning liver mass-comparable to an extended right liver graft.

Criteria for MHV reconstruction

It remains unclear whether all modified right liver grafts without the MHV trunk require MHV reconstruction. Lee and colleagues [20] emphasised aggressive reconstruction of MHV under any circumstances. However, most of the initial cases [10, 17, 18] using a modified right liver graft seemed to achieve successful results without MHV reconstruction.

Sano and associates [24] proposed clear criteria for MHV reconstruction. Hepatic venous congestion in the right paramedian sector was investigated intraoperatively

after parenchyma transection. First, liver surface discoloration in the right paramedian sector was observed after simultaneous clamping of MHV tributaries and the right hepatic artery for 5 min. Next, intraoperative Doppler ultrasonography was performed after declamping only the hepatic artery. If the portal flow of the paramedian sector was hepatofugal, this confirmed that the area was congested. All of the examinations for checking venous congestion can be completed in 10 minutes in experienced hands.

If the congested area is dominant, based on the clamping test or ultrasonography, we have proceeded with bench reconstruction of MHV tributaries. The necessity of inferior right hepatic vein reconstruction was determined using the same criteria. MHV tributaries were reconstructed under these criteria in our series [25]. Reconstruction was performed in 18 of 30 grafts, and all the grafts had an uneventful functional recovery. As our experience of MHV reconstruction under the criteria has been limited, the feasibility must be confirmed in a larger number of cases in the future.

Right lateral sector graft

A right lateral sector graft (segments VI and VII according to Couinaud's nomenclature for liver segmentation) was devised recently [26]. The details of the harvesting technique are as follows. Occlusion of the right paramedian and left branches of the portal veins and hepatic arteries reveal the demarcation line on the liver surface. The dissection plane is 5 mm to the left of the right portal fissure. Liver transection is performed using a Kelly clamp under occlusion of the right paramedian branches of the portal veins and hepatic arteries. The right lateral bile duct is then identified by intraoperative cholangiography before liver transection.

The procedure is indicated when the right liver is >70% of the estimated volume of the whole donor liver and the estimated right lateral sector volume is greater than that of the left liver [27]. Recent volumetric analysis [28] of donors revealed that 72% had a larger right lateral sector than a left liver with caudate lobe when the volume of the right liver was estimated to be >70% of the whole.

Dual grafts

Lee and associates [29] recently reported an innovative technique in LDLT, which could make up for graft size insufficiency and secure the donor's safety. Left liver grafts were harvested from two living donors, which were then implanted into one recipient. This procedure may be indicated in a particular situation. Donors should have a large right liver while the remaining left liver is too small to maintain life. The recipient is in the advanced stage of liver disease and needs >40% of the standard liver volume. The risks for the recipient and donors are also doubled in this procedure, although the results of the reported cases were quite satisfactory in their series of 17 patients [30]. The procedure should be limited to specific circumstances from the point of view of economic cost and medical labour: three operating theatre rooms and three surgical teams are required for the technique.

The Kyoto group [31] implanted dual grafts in one patient; so far, no other groups have reported experience of dual grafts.

Conclusions

A right liver graft seems to alleviate the small-for-size problem in LDLT for adults. The procedure imposes greater surgical risk for living donors and is associated with an increased mortality rate. The patients who truly need a right liver graft should be selected using evidence-based criteria. Secure hepatic vein reconstruction is one of the most crucial factors in the recipient [32]. To obtain satisfactory functional reserve of the hemi-liver graft, aggressive vein reconstruction using our criteria is required.

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References

- 1 Strong RW, Lynch SV, Ong TH, Matsunami H, Koido Y, Balderson GA. Successful liver transplantation from a living donor to her son. *N Engl J Med* 1990;322: 1505-7.
- 2 Tanaka K, Inomata Y. Present status and prospects of living-related liver transplantation. *J Hep Bil Pancr Surg* 1997;4:51-70.
- 3 Hashikura Y, Makuuchi M, Kawasaki S, et al. Successful living-related partial liver transplantation to an adult patient. *Lancet* 1994;343:1233-4.
- 4 Cronin DC, 2nd, Millis JM, Siegler M. Transplantation of liver grafts from living donors into adults-too much, too soon. *N Engl J Med* 2001;344:1633-7.
- 5 Kawasaki S, Makuuchi M, Matsunami H, et al. Living related liver transplantation in adults. *Ann Surg* 1998;227:269-74.
- 6 Kiuchi T, Kasahara M, Uryuhara K, et al. Impact of graft size mismatching on graft prognosis in liver transplantation from living donors. *Transplantation* 1999;67:321-7.
- 7 Urata K, Kawasaki S, Matsunami H, et al. Calculation of child and adult standard liver volume for liver transplantation. *Hepatology* 1995;21:1317-21.
- 8 Lo CM, Fan ST, Liu CL, et al. Minimum graft size for successful living donor liver transplantation. *Transplantation* 1999;68:1112-16.
- 9 Sugawara Y, Makuuchi M, Takayama T, et al. Small-for-size grafts in living-related liver transplantation. *J Am Coll Surg* 2001;192:510-13.
- 10 Marcos A, Fisher RA, Ham JM, et al. Right lobe living donor liver transplantation. *Transplantation* 1999;68:798-803.
- 11 Ben-Haim M, Emre S, Fishheim TM, et al. Critical graft size in adult-to-adult living donor liver transplantation: impact of the recipient's disease. *Liver Transpl* 2001;7: 948-53.
- 12 Miyagawa S, Hashikura Y, Miwa S, et al. Concomitant caudate lobe resection as an option for donor hepatectomy in adult living related liver transplantation. *Transplantation* 1998;66:661-3.
- 13 Takayama T, Makuuchi M, Kubota K, Sano K, Harihara Y, Kawarasaki H. Living-related transplantation of left liver plus caudate lobe. *J Am Coll Surg* 2000;190:635-8.
- 14 Sugawara Y, Makuuchi M, Kaneko J, Ohkubo T, Matsui Y, Imamura H. New venoplasty technique for the left liver plus caudate lobe in living donor liver transplantation. *Liver Transpl* 2002;8:76-7.
- 15 Couinaud C. The paracaval segments of the liver. *J Hep Bil Pancr Surg* 1994;2:145-9.
- 16 Sugawara Y, Makuuchi M, Takayama T. Left liver plus caudate lobe graft with complete re-vascularization. *Surgery* 2002;132:348-52.
- 17 Yamaoka Y, Washida M, Honda K, et al. Liver transplantation using a right lobe graft from a living related donor. *Transplantation* 1994;57:1127-30.
- 18 Wachs M, Bak T, Karrer F, et al. Adult living donor liver transplantation using a right hepatic lobe. *Transplantation* 1998;66:1313-16.
- 19 Marcos A, Ham JM, Fisher RA, et al. Surgical management of anatomical variations of the right lobe in living donor liver transplantation. *Ann Surg* 2000;231:824-31.
- 20 Lee S, Park K, Hwang S, et al. Congestion of right liver graft in living donor liver transplantation. *Transplantation* 2001;71:812-4.
- 21 Cattral MS, Greig PD, Muradali D, et al. Reconstruction of middle hepatic vein of a living-donor right lobe liver graft with recipient left portal vein. *Transplantation* 2001;71:1864-6.
- 22 Ghobrial RM, Hsieh CB, Lerner S, et al. Technical challenges of hepatic venous outflow reconstruction in right lobe adult living donor liver transplantation. *Liver Transpl* 2001;7:551-5.
- 23 Lee SG, Min Park K, Hwang S, et al. Modified right liver graft from a living donor to prevent congestion. *Transplantation* 2002;74:54-9.
- 24 Sano K, Makuuchi M, Miki K, et al. Evaluation of hepatic venous congestion: proposed indication criteria for hepatic vein reconstruction. *Ann Surg* 2002;236:241-7.
- 25 Sugawara Y, Makuuchi M, Sano K, et al. Vein reconstruction in modified right liver graft for living donor liver transplantation. *Ann Surg*:(in press).
- 26 Sugawara Y, Makuuchi M, Takayama T, et al. Liver transplantation using a right lateral sector graft from a living donor to her granddaughter. *Hepatogastroenterology* 2001;48:26i-3.
- 27 Sugawara Y, Makuuchi M, Takayama T, Imamura H, Kaneko J. Right lateral sector graft in adult living-related liver transplantation. *Transplantation* 2002;73:111-14.
- 28 Leelaudomlipi S, Sugawara Y, Kaneko J, Matsui Y, Ohkubo T, Makuuchi M. Volumetric analysis of liver segments in 155 living donors. *Liver Transpl* 2002;8:612-14.
- 29 Lee SG, Hwang S, Park KM, et al. An adult-to-adult living donor liver transplant using dual left lobe grafts. *Surgery* 2001;129:647-50.
- 30 Lee SG, Hwang S, Park KM, et al. Seventeen adult-to-adult living donor liver transplantations using dual grafts. *Transplant Proc* 2001;33:3461-3.
- 31 Kaihara S, Ogura Y, Kasahara M, Oike F, You Y, Tanaka K. A case of adult-to-adult living donor liver transplantation using right and left lateral lobe grafts from 2 donors. *Surgery* 2002;131:682-4.
- 32 Sugawara Y, Makuuchi M. Expectations and limitations in adult-to-adult living-related liver transplantation. *Asian J Surg* 2001;24:5-6.