Transplantation

Technical considerations of living donor hepatectomy of segment 2 grafts for infants

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Background. *The selection of an adequate graft to mitigate the problems associated with a large-for-size graft is essential to ensure the success of liver transplantation for smaller children. Reduced left lateral segment (LLS) grafts have been introduced to overcome this issue.*
Methods. *Five infants underwent living donor liver transplantation (LDLT) with segment 2 grafts. In the preoperative assessment, the graft-to-recipient weight ratio (GRWR) and the ratio of the thickness of the donor LLS were used as a reference index for graft size matching, and a 3-dimensional (3D) computer-generated model of the donor liver was used for the analysis of the intrahepatic vasculature. During the donor operation, the relevant portal vein branches feeding to the reduced part of segment 3 were first exposed and divided, and then the parenchymal transection was performed.*
Results. *Segment 2 grafts were selected in 3 cases and reduced segment 2 grafts were selected in the other 2 cases. The graft reduction was achieved with $46.6 \pm 8.2\%$ of the actual LLS, and thus the GRWR was reduced from $5.33 \pm 2.09\%$ to $2.70 \pm 0.82\%$. The actual graft thickness was reduced by approximately half after the graft reduction. Primary abdominal closure was performed in all of the recipients. No surgical complications occurred in any of the donors or recipients.*
Conclusion. *A segment 2 graft could be a valuable option for graft type selection in LDLT for smaller children. Precise planning using a 3D computer-generated model of the donor liver and meticulous operative procedures are necessary to obtain a viable graft. (Surgery 2014;156:1232-7.)*

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THE GRAFT-TO-RECIPIENT WEIGHT RATIO (GRWR)—percentage of graft volume to recipient body weight—has been used as a simple reference index for graft size matching in living donor liver transplantation (LDLT), and a significant correlation between the outcomes of LDLT and the GRWR has been confirmed.[1] The left lateral segment (LLS) from an adult donor can be too large for a small infant when the GRWR is >4.0%, and thus may result in a large-for-size graft and its associated morbidity.[2] The problems related to large-for-size grafts have been overcome by the introduction of further reduced LLS grafts for smaller children,[3,4] although graft thickness remains a problem because the strategy employs a simple nonanatomic reduction of the lateral and/or caudal part of the LLS.

A segment 2 graft has been recently introduced as an alternative graft, and excellent outcomes of infantile LDLT were reported.[5,6] However, living donor hepatectomy of a segment 2 graft can be technically demanding in comparison with that of a nonanatomically reduced LLS graft. Despite the technical difficulties, this graft option

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Table I. The characteristics of the recipients and donors

Recipient case no.	Age at LDLT (mo)	Gender	Body weight (kg)	Original liver disease	Relationship to donor	Donor age (y)	Donor body weight (kg)
1	5	Female	5.48	BA	Mother	36	58.4
2	14	Male	9.4	MMA	Father	36	75
3	6	Male	6.59	BA	Father	36	84.4
4	4	Female	4	BA	Father	28	58
5	4	Female	5.47	BA	Mother	32	57.3

BA, Biliary atresia; *LDLT*, living donor liver transplantation; *MMA*, methylmalonic acidemia.

obviously has advantages in that it reduces the graft thickness to avoid the problems related to large-for-size grafts.

We previously reported satisfactory outcomes of LDLT with nonanatomically reduced LLS grafts[3] and a preliminary report of a case of neonatal LDLT with a segment 2 graft.[4] We herein present 5 LDLT cases treated with segment 2 grafts, focusing on the preoperative planning and operative procedures, and propose an algorithm to select the graft type for LDLT for smaller children.

PATIENTS AND METHODS

From November 2005 to September 2013, 53 recipients underwent LDLT by receiving reduced LLS grafts at our institute. Among them, segment 2 grafts were introduced for 5 infant cases (2 males and 3 females). The median age at LDLT was 5 months (range, 4–14). The body weight at LDLT was 6.2 ± 2.0 kg (range, 4.0–9.4). The original liver diseases included biliary atresia in four cases and methylmalonic academia in 1 case. All of the donors were one of the infants' parents, consisting of 3 fathers and 2 mothers, with a median age of 36 years (range, 28–36). The body weight was 66.6 ± 12.4 kg (range, 57.3–84.4). The characteristics of the recipients and donors are summarized in Table I. All data are presented as median values or mean values ± standard deviations.

Preoperative assessment for graft type selection (Fig 1). The first step of graft type selection for a small infant was made based on the volume and the shape of a graft. From the perspective of the graft volume, the estimated GRWR was calculated using preoperative computed tomography volumetry. If the estimated GRWR of the LLS of the donor was >4.0%, reduction of the LLS was considered. From the perspective of the graft shape, if the LLS of the donor was bulky, and its maximum thickness was larger than the anteroposterior (AP) diameter in the recipient's abdominal cavity, which was identified as the length from the inside abdominal wall to the front of the vertebra on axial computed tomography images, a segment 2 graft was considered.
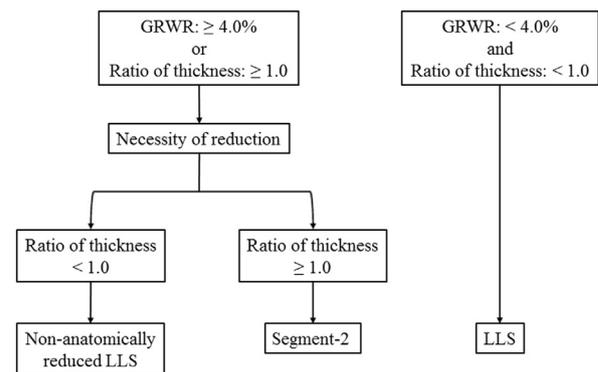

Fig 1. Algorithm used for the preoperative assessment for graft type selection. *GRWR*, Graft-to-recipient weight ratio; *LLS*, left lateral segment; *ratio of thickness*, the ratio of the maximum thickness of the LLS to the anteroposterior diameter in the recipient's abdominal cavity.

If the LLS of the donor extended laterally, a further reduction of its lateral portion was considered.

The next step in graft type selection was made based on the anatomic patterns of the portal veins (PV) and the hepatic veins (HV). Three-dimensional (3D) computer models of the donor livers were generated (MeVis Medical Solutions AG, Bremen, Germany). After considering the anatomic patterns of the PV, the reduction of segment 3 was selected to adjust the graft thickness. For example, if the PV branch feeding to segment 2 was tenuous, and/or the PV branches feeding to the dorsal part of segment 3 were present (Fig 2, A), the main PV pedicle of segment 3 was preserved. In terms of the anatomic patterns of the HV, if the tributaries from segment 2 drained into the main left HV, the trunk of the left HV was preserved (Fig 2, B).

Operative procedure. During the donor operation, an upper midline incision was made from the end of xiphoid process. After the isolation of the donor's left hepatic artery and left PV, the hepatic parenchyma was transected 5 mm to the right of the falciform ligament, just as in standard donor hepatectomy of the LLS.[7] A further reduction of
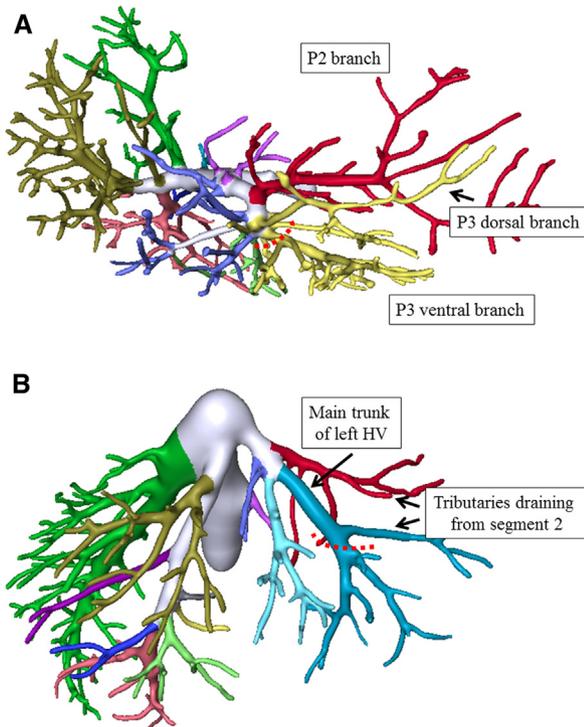
Fig 2. Three-dimensional, computer-generated models of the donor's livers. The model of case 5 revealed multiple portal vein branches feeding to segment 3 (P3), the dorsal branch of which was preserved, with the portal vein branch feeding to segment 2 (P2), which affected the functional graft volume (*A*, cranial view). The model of case 4 revealed that the tributaries from segment 2 drained into the main left hepatic vein (HV), and thus, the trunk of left HV was preserved (*B*). *Red dotted lines* show the cutting lines for sacrificed pedicles of the P3 branches and the tributaries draining from segment 3. (Color version of figure is available online.)

the LLS to reduce the graft thickness was performed in situ. Each PV branch feeding to segment 3 and 4 was separately exposed by following the round ligament toward the hepatic parenchyma (Fig 3, *A*). According to the preoperative assessment of the anatomic patterns of the PV, the relevant PV branches feeding to the part of segment 3 that would be reduced were occluded to make demarcation lines on the surface between segment 2 and 3 (Fig 3, *B*). At that point, intraoperative Doppler ultrasonography could visualize the portal venous flow feeding to the graft, which was planned to be preserved inside the liver. The further transection of the hepatic parenchyma was performed horizontally, following those demarcation lines. During that procedure, care was taken to preserve the drainage veins of the graft. If further reduction from the perspective of the graft volume was necessary, the removal of

the lateral part of segment 2 was added. During the recipient operation, all of the vascular and biliary reconstructions were performed as in standard pediatric LDLT (Fig 3, *C*).

RESULTS

The graft type selection and donor outcomes (Table II). The first step of preoperative assessment showed that the estimated GRWR of the LLS ranged from 2.49 to 7.67%, and the ratio of the thickness of the LLS to the AP diameter in the recipient's abdominal cavity ranged from 1.01 to 1.55. According to the next step of preoperative assessment, there were separate branches feeding to segment 3, and thus, its dorsal branches were planned to be preserved in 2 cases (Cases 4 and 5). As a result, segment 2 grafts were selected in 3 cases and segment 2 grafts with further reduction of the lateral part were selected in 2 cases. Graft reduction was successfully achieved with 46.6 ± 8.2% of the actual LLS; thus, the GRWR was reduced to 2.70 ± 0.82%. The ratio of the thickness of the actual graft to the AP diameter in the recipient's abdominal cavity ranged from 0.44 to 0.79, amounting to 50.0 ± 11.4% of the ratio of the thickness of the LLS before the graft reduction. The duration of the donor operation was 294.4 ± 19.8 minutes, and the estimated blood loss was 196.2 ± 114.3 mL, without the need for transfusion in any of the cases. All donors were discharged without any complications at a median of postoperative day 7 (range, 7–9).

Recipient outcomes (Table II). The duration of the recipient operation was 505.0 ± 63.0 minutes, and the estimated blood loss was 312.0 ± 181.9 mL. PV reconstruction with an interposition graft using the donor's inferior mesenteric vein was performed in 1 case (Case 4). Primary abdominal closure was able to be performed in all of the recipients. The postoperative clinical courses in all of the recipients were uneventful without any operative complications, and all of them are doing well with a median follow-up period of 6 months (range, 4–12).

DISCUSSION

The major problems related to large-for-size grafts are the insufficient blood flow to the revascularized liver and the small size of the recipient's abdominal cavity, which lead to inadequate tissue oxygenation and graft compression, possibly resulting in vascular complications and graft dysfunction.[2] The use of synthetic mesh and secondary closure is necessary to avoid graft compression, although these procedures may increase the risk of infectious complications involving the abdominal
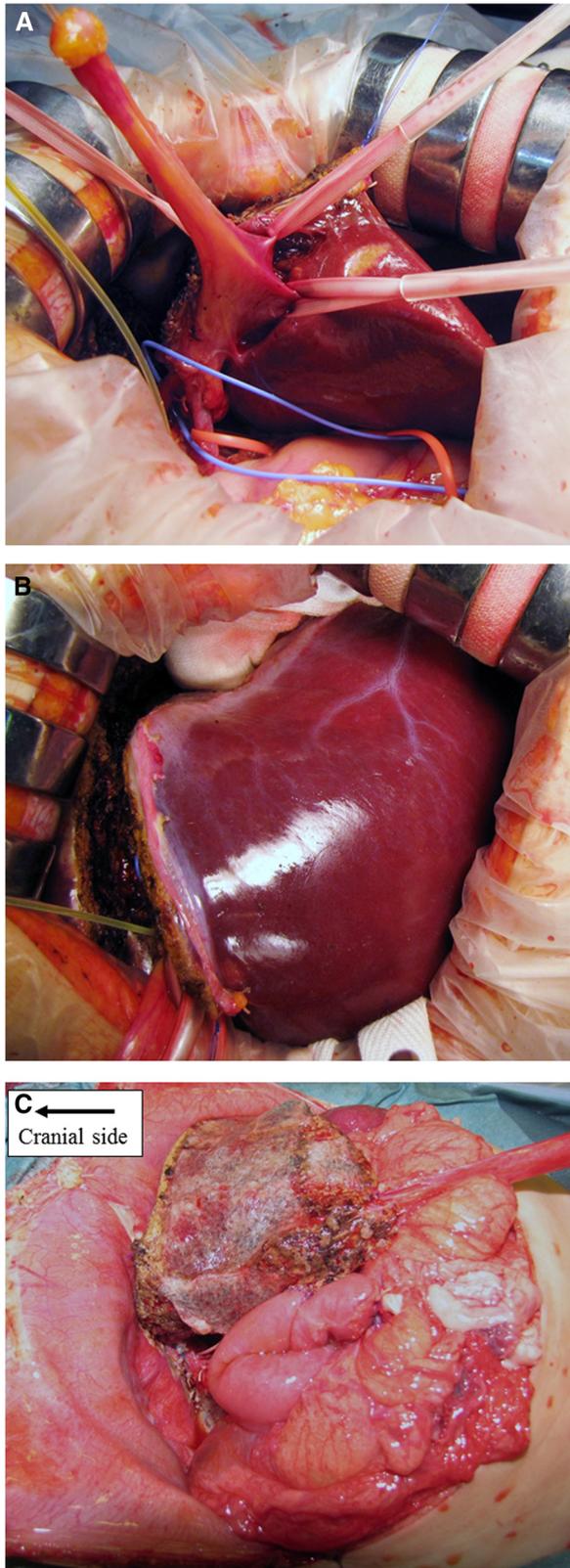
wall.[8,9] Furthermore, abdominal distension, simply caused by large-for-size grafts, can cause respiratory complications, and may lead to delayed extubation.[1,2] The prevention of such problems makes it necessary to reduce not only the net volume, but also the thickness of the graft. According to the previous reports of monosegmental liver transplantation, the graft types included a nonanatomically reduced LLS graft, mainly consisting of segment 3, and an anatomically reduced LLS graft of segment 2.[2,4-6,8-13] The Kyoto group recently reported that the long-term outcomes in LDLT using nonanatomically reduced LLS graft were acceptable with relatively low incidence of vascular complications and the univariate analysis of prognostic factors for patient and graft survival did not reveal any difference by the GRWR, as a reference index for the reduction of the net volume.[4] Although the net volume of the graft can be appropriately reduced by using nonanatomically reduced LLS grafts, adequate reduction of the thickness of the graft may be achieved by using segment 2 grafts rather than non-anatomically reduced LLS grafts.[2,5,6]

Living donor hepatectomy of a segment 2 graft can be technically demanding, and therefore requires precise operative planning and procedures. A recently reported article clearly demonstrated the usefulness of 3D computer-assisted operative planning in adult-to-adult LDLT, especially focusing on the functional graft/remnant liver volumes related to the HV drainage territories.[14] The current study similarly showed that a preoperative analysis using a 3D computer-generated model of the donor's liver was valuable to understanding the anatomic patterns of the intrahepatic vasculature in infantile LDLT. The evaluation of the anatomic patterns of the PV was particularly important to tailor the graft size from the aspect of not only the thickness, but also of the functional volume of the graft. In terms of the intraoperative procedures for living donor hepatectomy of a segment 2 graft, it is crucial to identify and avoid injuring the portal pedicles during the hazardous dissection at the base of the umbilical fissure.[13] Separate exposure and occlusion of the relevant PV pedicles feeding to the reduced part of segment 3 and making demarcation lines between segments 2 and 3 is important to perform an anatomically accurate reduction, and intraoperative ultrasonography may further assist in the

Fig 3. The operative procedures performed during the donor operation and recipient operation using a segment 2 graft. During the donor operation, each portal vein branch feeding to segments 3 and 4 was separately exposed (*A*) and occluded to make demarcation lines on the surface between segments 2 and 3. (*B*) During the recipient operation, the segment 2 graft was implanted in the abdominal cavity (*C*).

Table II. The graft type selection and the outcomes

Recipient case no.	Estimated GRWR (%)	Thickness of LLS/AP diameter of abdomen	Graft type	Actual graft weight (g)	Actual GRWR (%)	Reduction rate (%)	Thickness of graft/AP diameter of Abdomen	Recipient's outcome (follow-up period)
1	5.26	1.01	S2	127	2.32	55.75	0.59	Alive (1 y)
2	2.49	1.55	S2	138	1.47	39.21	0.63	Alive (7 mo)
3	4.25	1.09	S2	194	2.94	37.22	0.44	Alive (6 mo)
4	7.67	1.09	Reduced-S2	138	3.45	47.53	0.49	Alive (5.5 mo)
5	6.98	1.20	Reduced-S2	182	3.33	53.09	0.79	Alive (3.5 mo)

AP, Anteroposterior; *GRWR*, graft-to-recipient weight ratio; *LLS*, left lateral segment; *S2*, segment 2.

transection of the hepatic parenchyma as a navigational guide.[15,16] 3D printing technology has been introduced into the field of LDLT as a new technology, and real 3D-printed liver models can provide important information that may influence the operative planning and potentially decrease complications intraoperatively.[17] This technology may be useful in the setting of pediatric LDLT, especially for smaller recipients, to reduce the problems associated with a large-for-size graft, if the recipient's abdominal cavity is also printed to test whether a 3D-printed model of the planned graft can fit in the recipient's abdominal cavity before the operation.[18]

The current study proposes a novel algorithm that can be used to select the graft type in LDLT for smaller children, which is simply framed in terms of the GRWR and the ratio of the thickness of the LLS to the AP diameter in the recipient's abdominal cavity. Furthermore, performing a preoperative analysis using a 3D, computer-generated model of the donor's liver can provide valuable information for the decision-making process in regard to graft type selection. As shown in Fig 1, if the maximum thickness of the donor's LLS is smaller than the AP diameter in the recipient's abdominal cavity (ratio of thickness < 1.0), then segment 2 grafts may not be necessary for the majority of recipients. However, if a recipient is associated with a profoundly ill status before the operation, and shows severe subcutaneous edema of the abdominal wall or edematous intestines, then a nonanatomically reduced LLS is unlikely to fit into the small abdominal cavity of the child.[5] Therefore, the algorithm proposed in the current study should be refined through the further accumulation of experience, especially considering various preoperative conditions of the recipients as reference indices for graft type selection.

A segment 2 graft could be a valuable option for graft type selection in LDLT for smaller children, because it can help to overcome the problems related to large-for-size grafts. Precise planning by using a 3D computer-generated model of the donor's liver and meticulous operative procedures are necessary to obtain an anatomically and functionally viable graft.

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