Efficacy of CT Angiography for Preoperative Vascular Mapping in Adult to Adult Living Related Liver Transplant Donors

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Objective: *To assess the utility of CT angiography (CTA) in preoperative mapping of hepatic vascular anatomy in adult-to-adult living related liver transplant (LRLT) donors.*
Material and Method: *Over a 3-year period, 32 potential LRLT donors underwent CTA with subsequent comparison studies [digital subtraction angiography (DSA) and/or transplantation] were included in this study. Their CTA reports were retrospectively correlated with available DSA and/or operative findings.*
Results: *CTA correctly predicted right lobe arterial and portal venous anatomy in 32/32 (100%) donors. In 27 donors, hepatic venous anatomy on CT was compared with operative findings. The hepatic veins were well opacified in 23/27 (85.2%) donors. Of these, 15/16 (93.8%) significant (≥ 5 mm) accessory right hepatic veins and 11/11 (100%) significant segment VIII vein draining to middle hepatic vein were detected.*
Conclusion: *CTA provided an excellent preoperative depiction of hepatic vascular anatomy in LRLT donors.*

Keywords: *Liver transplantation, Computed tomography (CT) angiography, Digital subtraction angiography*

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Living related liver transplantation (LRLT) has emerged as an alternative life-saving procedure for adult patients with end-stage liver diseases because of the shortage of cadaveric organs[1-3]. Unlike pediatric LRLT recipients in whom the left lateral segment is used, adult LRLT recipients require the larger hepatic volume provided by the right lobe to assure the adequate liver function and reserve. However, right lobe resection is more challenging for the surgeon in part due to variable nature of vascular and biliary anatomy[4]. Donor livers with complex vascular anatomy, which necessitate complex vascular reconstruction, may be excluded from the donor list. In some cases, variant vessels may be ligated or anastamosed to larger normal vessels to prevent postoperative complications such as hepatic graft ischemia or congestion[1-3].

The primary goal of preoperative imaging in LRLT donors is to accurately identify normal and variant hepatic arterial and portal venous supply to the right lobe and additionally map the hepatic venous drainage[5,6]. Although conventional digital subtraction angiography (DSA) has been acknowledged as a gold standard for preoperative hepatic arterial and portal venous mapping, it is an invasive procedure and does not provide information about hepatic venous anatomy[7,8]. Additional preoperative studies are required to determine hepatic venous anatomy and other critical information such as donor lobar volume, biliary anatomy and parenchymal steatosis[6,9,10]. Obtaining all relevant preoperative information with a single noninvasive imaging study such as CT or MRI is preferable. The purpose of the present study was to prospectively compare the performance of hepatic CT

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angiography (CTA) to DSA and/or intraoperative findings in the preoperative mapping of normal and variant hepatic arterial, portal venous and hepatic venous anatomy in LRLT donors.

Material and Method

Potential LRLT donors

The present study was approved by the authors' institutional review board (IRB). Between August 1999 and October 2002, 72 potential LRLT donors underwent preoperative CTA at the authors' institution. Of these, only 32 potential donors had the subsequent comparison studies; either DSA or right lobe resection for LRLT (with surgical and available intraoperative ultrasound findings). In the study group, there were 20 men and 12 women with a mean age of 37.03 and a range of 22-54 years.

Overall, 22 of 32 (68.8%) of potential donors had conventional DSA for comparison with CTA. Of donors with DSA, 17 of 22 (77.3%) also underwent surgical inspection and intraoperative sonography. Since October 2001, based on preliminary results of the initial 22 donors that showed the high accuracy of CTA, DSA was no longer performed on potential donors. The last 10 LRLT donors underwent only preoperative CTA and the results were compared to operative findings and intraoperative sonography.

CT angiography

In 17 donors, CTA was performed on single detector helical scanners (SDCT) (CT/i; General Electric Medical Systems, Milwaukee, WI) and in 15 donors, on a 4-row multidetector helical scanner (MDCT) (LightSpeed Qx/i; General Electric Medical Systems, Milwaukee, WI). An unenhanced axial CT scan through the liver was performed axially at 10 mm collimation in order to determine the level of the celiac axis, assess hepatic steatosis and lobar volume. A timing run was then performed at the celiac axis to determine the true arterial phase. Using a power injector, 125-150 cc of Iohexol, (Omnipaque 350, Amersham Health Inc, Princeton, NJ; dose per weight) was injected at a rate of 4-5 cc/second. The true arteriographic sequence was obtained volumetrically as follows: SDCT: 3 mm collimation at 1.5 mm collimation interval, pitch 1.5:1, 120 kVp and 250 mA; MDCT: 1.25 mm x 4 at 0.6 mm interval, gantry rotation speed of 0.8 sec, table speed of 1 cm/sec, 120 kVp and 250 mA. The venous phase was performed at 60 seconds in the first four cases and modified to a 70-second time delay in subsequent cases. The venous phase parameters were as follows: SDCT: 5 mm collimation at 2.5 mm interval; MDCT: 2.5 mm collimation; table speed 1.5 cm/gantry rotation.

All studies were reviewed and post processed on a dedicated, commercially available three-dimensional (3-D) workstation (Vitrea, Vital Images Inc., Plymouth, MN). Three-dimensional reconstructions of hepatic vessels were rendered with multiplanar reformation (MPR), maximum intensity projection (MIP), and volume-rendered technique (VRT). Preoperative hepatic CTA was interpreted prospectively by one of three experienced abdominal imagers without the knowledge of conventional DSA findings. On each report the following was described: number and origin of right hepatic arteries, number and origin of segment IV arteries, portal venous anatomy, hepatic venous anatomy including significant ($\geq$ 5 mm) accessory right hepatic veins and significant ($\geq$ 5 mm) segment VIII veins draining to middle hepatic vein.

Conventional DSA

In the first 22 cases, conventional DSA was performed and interpreted prospectively by one of three experienced angiographers blinded to the results of hepatic CTA using standard technique with a variety of five French catheters. Using iohexol (Omnipaque 350, Amersham Health Inc, Princeton) in general and the following views were acquired: abdominal aortography (40 cc; 20 cc/sec), selective celiac arteriography with portovenous phase (25-30 cc; 5-7 cc/sec), selective superior mesenteric arteriography with portovenous phase (30 cc; 3 cc/sec) and selective left gastric arteriography.

LRLT and intraoperative ultrasound

For adult-to-adult LRLT, a cholecystectomy was performed followed by resection of Couinaud segments V, VI, VII, and VIII. The avascular plane for right lobe resection (Cantlie's line) was identified intraoperatively by sonography (8 mHz transducers; ATL 3000-5000; Phillips, Bothell, WA) using the line just lateral to middle hepatic vein and extending inferiorly to the bifurcation of portal vein. The intraoperative ultrasound was performed by one of three experienced sonographers, generally blinded to results of CTA. On each report, sonographic appearance of hepatic venous anatomy was noted. All significant vascular and biliary structures supplying and draining right lobe were identified intraoperatively and preserved for subsequent anastomoses in recipient. The surgical and intraoperative ultrasound findings of hepatic vasculatures were reported.

Data analysis

The preoperative CTA reports were retrospectively compared with available preoperative DSA, surgical, and intraoperative ultrasound findings to identify the ability of preoperative CTA for predicting hepatic arterial, portal venous and hepatic venous anatomy. For preoperative mapping of hepatic arterial and portal venous anatomy, CTA findings in all 32 cases were compared against conventional DSA and/or operative findings (surgical inspection and intra-operative ultrasound). For preoperative mapping of hepatic venous anatomy, CTA was compared against operative findings in the 27 of 32 cases who underwent LRLT.

Results

Hepatic arterial anatomy

The hepatic arterial anatomy variations demonstrated by preoperative CTA, conventional DSA, and operative findings were illustrated in Table 1. Overall, preoperative CTA correctly predicted right hepatic lobe arterial anatomy in 32 (100%) donors when compared to conventional DSA and/or donor hepatectomy. In 23 (71.9%) donors, a standard single right hepatic artery (RHA) originated from the common hepatic artery (CHA) and celiac axis. In six (18.8%) donors, a single replaced RHA arose from the superior mesenteric artery (SMA). In a single donor, two RHA were detected, the larger aberrant artery from the SMA and the smaller artery arising from the CHA and celiac axis (Fig. 1). In two donors, a single RHA arose from a CHA aberrantly from the SMA (Fig. 2).

The origin of segment IV arteries was visualized in all 32 cases on CTA. Five donors had aberrant segment IV artery originating from RHA (Fig. 3) and they were correctly predicted (100%).

Portal venous anatomy

The portal venous anatomy variations demonstrated by preoperative CTA, conventional DSA, and operative findings were illustrated in Table 2. Overall, preoperative CTA correctly described portal venous anatomy in 32 (100%) donors when compared to conventional DSA and/or surgery. A

Table 1. Hepatic arterial anatomy variations demonstrated by preoperative CT angiography (CTA), conventional digital subtraction angiography (DSA), and operative findings

Anatomical variation	CTA (%)	DSA (%)	Operative findings (%)
Right hepatic artery			
Conventional	23/32 (71.9%)	16/22 (72.7%)	20/27 (74.1%)
Replaced RHA from SMA	6/32 (18.8%)	6/22 (27.3%)	4/27 (14.8%)
CHA from SMA	2/32 (6.2%)	-	2/27 (7.4%)
2 RHA	1/32 (3.1%)	-	1/27 (3.7%)
Total	32/32 (100%)	22/22 (100%)	27/27 (100%)
Seg IV artery			
Conventional	27/32 (84.4%)	19/22 (86.4%)	23/27 (85.2%)
From RHA	5/32 (15.6%)	3/22 (13.6%)	4/27 (14.8%)
Total	32/32 (100%)	22/22 (100%)	27/27 (100%)

RHA = right hepatic artery; SMA = superior mesenteric artery; CHA = common hepatic artery

Table 2. Portal venous anatomy variations demonstrated by preoperative CT angiography (CTA), conventional digital subtraction angiography (DSA), and operative findings

Anatomical variation	CTA (%)	DSA (%)	Operative findings (%)
Bifurcation	27/32 (84.4%)	17/22 (77.3%)	23/27 (85.2%)
Trifurcation	4/32 (12.5%)	4/22 (18.2%)	3/27 (11.1%)
LPV from RAPV	1/32 (3.1%)	1/22 (4.5%)	1/27 (3.7%)
Total	32/32 (100%)	22/22 (100%)	27/27 (100%)

LPV = left portal vein; RAPV = right anterior portal vein

Fig. 1 30-year-old male donor. On 3-D volume-rendered hepatic CTA, 2 right hepatic arteries were seen. One (arrows) arose normally from hepatic artery proper. A larger aberrant artery (arrowheads) originating from superior mesenteric artery was preoperatively identified and preserved at transplantation

Fig. 2 45-year-old female donor. On 3-D volume-rendered hepatic CTA, a single right hepatic artery (arrows) originated from an aberrant common hepatic artery (arrowheads) from superior mesenteric artery. This variants was confirmed at transplantation

bifurcation of the portal vein was present in 27 (84.4%) cases (Fig. 4a, 4b) and a trifurcation variant (Fig. 5a, 5b) was present in four (12.5%) cases. In one additional case, left portal vein originated from right anterior portal vein was noted.

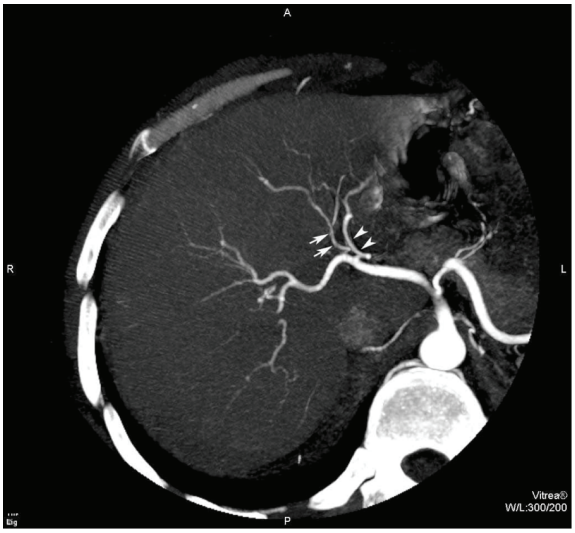

Fig. 3 29-year-old male donor. On 2-D axial multiplanar-reformatted hepatic CTA, an aberrant origin of main segment IV artery (arrows) from right hepatic artery was shown. Notice the cross perfusion between segment II-III (arrowheads) and segment IV artery

Hepatic venous anatomy

In the subset of 27 donors who underwent a right hepatectomy, the hepatic veins were well opacified on CT in 23 (85.2%) cases. In four early cases, the venous phase acquired at 60-second delay had non-opacified hepatic veins and were considered as technical failures. In these four cases, one significant ($\geq$ 5 mm) accessory right hepatic vein (RHV) draining posteroinferior right lobe to inferior vena cava (IVC), and one significant ($\geq$ 5 mm) segment VIII vein draining to middle hepatic vein (MHV) were missed by CT, but were found and preserved at surgery. Due to this initial experience, the venous phase acquisition was delayed to 70 seconds, achieving adequate hepatic venous opacification in 23 subsequent cases. The significant hepatic venous anatomy variations demonstrated by preoperative CTA (in the following 23 cases) and operative findings were illustrated in Table 3. Overall, preoperative CTA correctly described 15 of 16 (93.8%) significant accessory RHV (Fig. 6a, 6b). In the missed case, the accessory right hepatic vein was present on retrospective review. Eleven of these 16 (68.8%) veins were considered surgically relevant and were preserved with creation of an extra anastomosis in the recipients.

Hepatic CT venography detected 11 (100%) significant ($\geq$ 5 mm) segment VIII vein draining to MHV

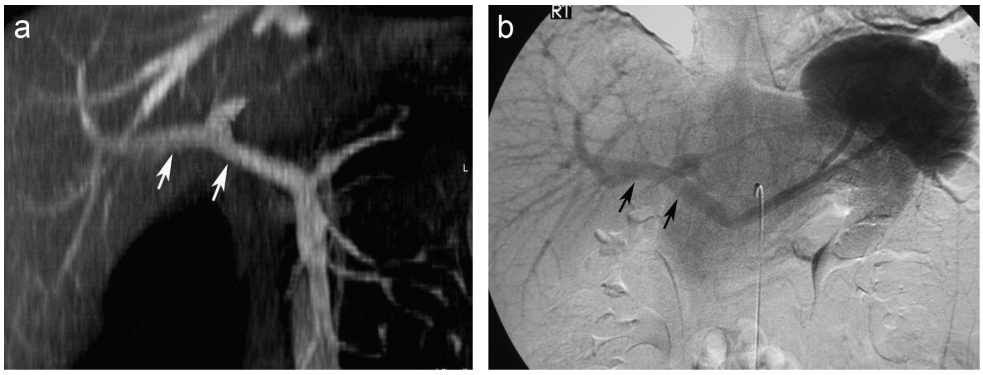

Fig. 4 47-year-old female donor. (a) 2-D coronal multiplanar-reformatted portal phase image demonstrated a normal bifurcation of portal vein (arrows) which was confirmed by conventional DSA and surgery, (b) Corresponding conventional DSA during portovenous phase of selective celiac arteriography confirmed normal bifurcation of portal vein (black arrows)

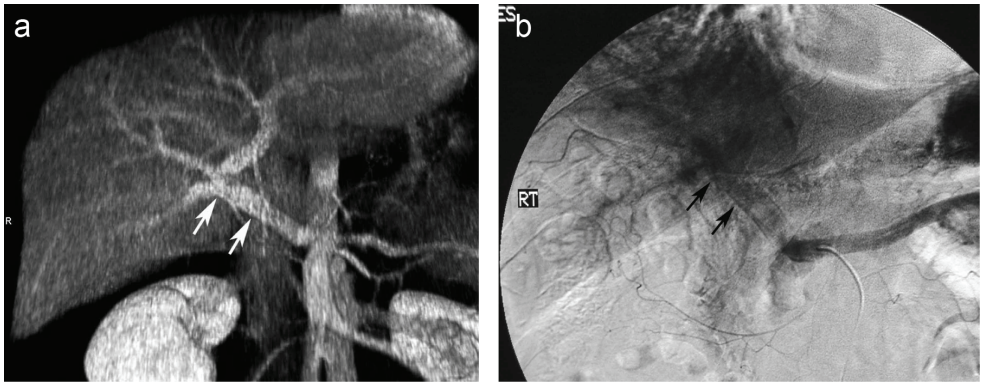

Fig. 5 54-year-old male donor. (a) 3-D volume-rendered portal CT venography demonstrated trifurcation of portal vein (arrows), (b) Corresponding conventional DSA during portovenous phase of selective celiac arteriography showed trifurcation of portal vein (black arrows). Notice insufficient resolution of indirect visualization of portal venous system, another weak point of conventional DSA

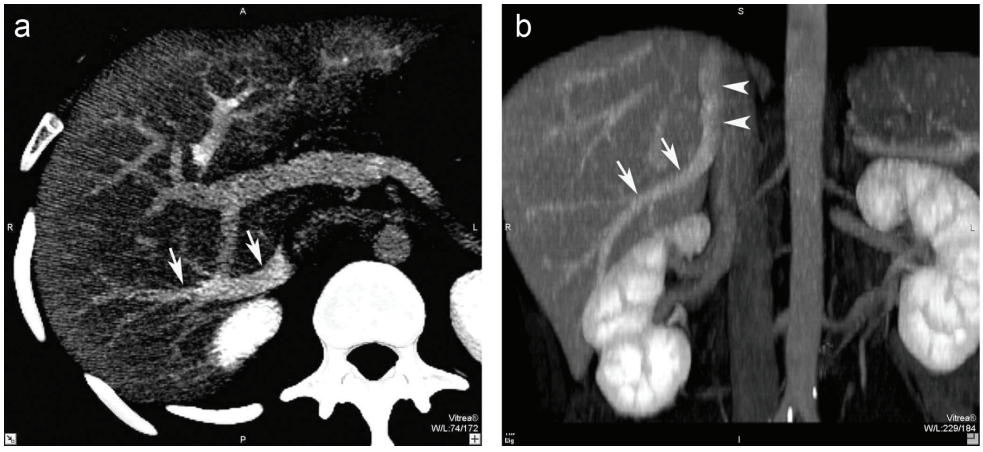

Fig. 6 35-year-old male donor. (a) 2-D axial multiplanar-reformatted hepatic CT venography demonstrated a significant (≥ 5mm) accessory right hepatic vein (arrows). This was identified and preserved at transplantation, (b) 2-D coronal multiplanar-reformatted hepatic CT venography demonstrated this accessory right hepatic vein (arrows) draining posteroinferior portion of right lobe to IVC (arrowheads)

Table 3. Hepatic venous anatomy variations demonstrated by preoperative CT angiography (CTA) and operative findings

Anatomical variation	CTA (%)	Operative findings (%)
≥ 5mm accessory RHV	15/23 (65.2%)	17/27 (63.0%)
≥ 5mm segment VIII vein	11/23 (47.8%)	12/27 (44.4%)

RHV = right hepatic vein

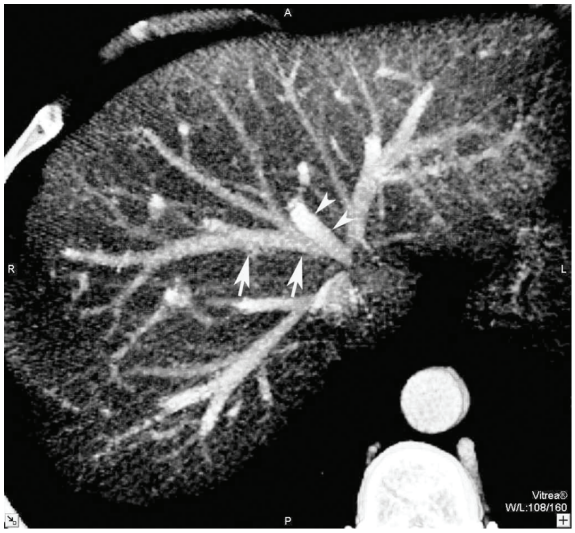

Fig. 7 40-year-old male donor. 2-D axial multiplanar-reformatted hepatic CT venography demonstrated a significant (≥ 5 mm) segment VIII vein (arrows) traversing the resection plane to middle hepatic vein (arrowheads). This was identified and preserved for extra anastomoses in the recipient

(Fig. 7). Five on these 11 (45.5%) veins were preserved at surgery.

Discussion

In the present study, the authors demonstrated the excellent agreement between CTA performed on single and multidetector scanners and conventional DSA and/or surgery. CTA, especially given advances in CT and post-processing technology, may eliminate the risk of invasive procedures such as conventional DSA in healthy donors. Similar results have been reported in prior studies[10-13], focused on a large group of LRLT donors.

Hepatic arterial anatomic variants are common, present in 24-45% of the population[1-3]. Variant right lobe anatomy may require additional surgical anastomoses in the recipient to prevent postoperative graft ischemia. In the donor, all arteries supplying left lobe must be preserved to prevent ischemia in the remaining left lobe. Most commonly, this involves identifying the origin of the often small segment IV artery[4-6] whether arising normally (from left hepatic artery) or aberrantly (from right hepatic artery). If aberrant, the segment IV artery traverses the anticipated resection plane, requiring the true resection plane to be shifted more peripherally. Lee et al[13] reported that in 11 of 62 (17.7%) 4-row MDCT angiography with an injection rate of 3 cc/second in potential Korean donors, the segment IV artery was not identified. In the present study, the authors preoperatively identified the origin of segment IV artery in all potential donors and correctly predicted aberrant segment IV artery originating from right hepatic artery in all five donors. This useful information prevented postoperative ischemia, which could be occurred in the presented donors. One may speculate that perhaps increasing the injection rate as 4-5 cc/second may help identifying these minute but important vessels. Lee et al[13] also identified the problem of respiratory motion artifact that compromised the visualization of hepatic arterial details in six of 62 donors (9.7%). To decrease this problem, respiratory training before the CTA study should be performed.

Although portal venous variants are much less common than hepatic arterial and venous variants, they are needed to be identified preoperatively since in some cases more than one anastomosis is required in the recipient[4-6]. Important variants include trifurcation (confluence of right posterior, right anterior and left to the main portal vein), right anterior branch originating from left portal vein and left branch originating from right anterior portal vein. In our series, five of 32 donors (15.6%) showed variant anatomy and were correctly identified prospectively on CTA. Although conventional DSA has been accepted as a gold standard for preoperative portal venous mapping, it is invasive and provides insufficient resolution of indirect visualization of portal venous system (Fig. 5b) comparing to portal CT venography (Fig. 5a).

Hepatic venous variants are slightly more common than portal vein variants, reported in approximately one-third of LRLT donors by sonography[9]. The significance of anatomic hepatic venous variants varies with surgeons' preferences and is not as well defined. At our institution, the plane of right lobe resection is identified during surgery by

intraoperative ultrasound using the line just right to the middle hepatic vein and extending inferiorly to the bifurcation of the portal vein. Thus, the middle hepatic vein is usually preserved in the donor and surgically relevant venous anomalies include 5 mm or larger tributaries from segment VIII or V draining into the middle hepatic vein, and accessory right hepatic veins 5 mm or larger draining posteroinferior portion of right lobe to IVC. However, some institutions use the resection plane, locating just left to the middle hepatic vein. Thus, the middle hepatic vein is included with the right lobe graft. In these cases, significant veins draining segment IVa and IVb to the middle hepatic vein should be identified. In the present series, the venous phase on CTA was acquired too early (60 second) for optimal hepatic venous enhancement in four earlier cases. With more optimal time delay (70 seconds), the authors' hepatic CT venography detected 93.8% significant ($\geq$ 5 mm) accessory right hepatic veins and 100% significant ($\geq$ 5 mm) segment VIII veins. Similar excellent results have been reported with regard to identifying hepatic venous anomalies in other studies[10,12].

CTA as part of a comprehensive CT examination offers a rapid, widely available, non-invasive means to obtain a variety of preoperative, clinically relevant information, including hepatic arterial and venous anatomy. At the authors' institution, this examination is currently performed exclusively on multidetector CT scanners and interpreted on an independent 3-D workstation by radiologists using multiplanar reformatting and volume rendering techniques. A dedicated 3-D technologist is able to perform post-processing showing relevant anatomic details with reasonable accuracy prior to radiologist interpretation. Approximately 10 minutes of radiologists' time is needed to interpret the examination. Although MDCT enables higher resolution images with shorter acquisition time and higher quality post processed images, it could be performed with a high accuracy for most patients on SDCT scanners.

Although CTA in LRLT evaluation has eliminated the need for DSA at the authors' institution and others, MR angiography (MRA) is a strong competitor in imaging for LRLT donors. MR imaging offers a comprehensive preoperative hepatic assessment of vascular, parenchymal and biliary anatomical information without ionizing radiation or potential morbidity of iodinated contrast material. In one study[14] which MRA (acquired with coronal gradient echo sequences of 5 mm thickness with 20% overlap by a 1.0-T scanner) was compared to DSA in 28 donors, one reviewer missed single replaced right hepatic arteries in two patients, while the other reviewer had one false positive of replaced right hepatic artery. In another study of 25 donors[15], MRA was performed with 3-D gradient-echo sequences with an effective slice thickness of 1.25-1.7 mm. Three of three patients with an aberrant segment IV artery were identified by MRA. In both studies, no significant portal or hepatic venous anomalies were missed. Although MRA is an attractive option, its resolution is currently not comparable with images obtained by MDCT. Furthermore, MRA is time-consuming and less available than CTA.

Limitations of the present study included small sample size that biased towards younger individuals considering living related liver donation in a North American population. Most studies were performed on older SDCT scanners with small variances in CT technique. However, the studies underwent post processing using relatively modern techniques on dedicated 3-D workstations by both technologists and interactively by radiologists. The authors expect that all aspects of the examination will improve with more advanced scanners and post processing software. Although prospective readings were compared against final outcome, the study was of retrospective design where only the first 22 cases underwent a DSA. However, because the readings were prospective, the analysis may be a better reflection of actual clinical practice.

In summary, CTA provided an excellent, noninvasive, preoperative hepatic vascular roadmap in adult-to-adult living related liver transplant (LRLT) donors. It may eliminate the need of more invasive study such as conventional DSA.

Potential conflict of interest

None.

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ประสิทธิภาพของการตรวจหลอดเลือดตับด้วยเครื่องเอกซเรย์คอมพิวเตอร์เพื่อใช้วางแผนการผ่าตัดในผู้บริจาคตับที่ยังมีชีวิตอยู่

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วัตถุประสงค์: *เพื่อศึกษาประสิทธิภาพของการตรวจหลอดเลือดตับด้วยเครื่องเอกซเรย์คอมพิวเตอร์เพื่อใช้วางแผนการผ่าตัดในผู้บริจาคตับที่ยังมีชีวิตอยู่*

วัสดุและวิธีการ: *ผลการตรวจหลอดเลือดตับด้วยเครื่องเอกซเรย์คอมพิวเตอร์ในผู้ที่มีโอกาสเป็นผู้บริจาคตับจำนวน 32 ราย ได้ถูกเปรียบเทียบกับผลการตรวจเพิ่มเติม (การใส่สายสวนเพื่อไปดูหลอดเลือดตับ หรือ การผ่าตัดเปลี่ยนตับ) เพื่อประเมินประสิทธิภาพของการตรวจหลอดเลือดตับด้วยเครื่องเอกซเรย์คอมพิวเตอร์*

ผลการศึกษา: *การตรวจหลอดเลือดตับด้วยเครื่องเอกซเรย์คอมพิวเตอร์สามารถทำนายลักษณะหลอดเลือดแดงตับและหลอดเลือดดำพอร์ตัลที่มีผลต่อการผ่าตัดได้ถูกต้อง 100% นอกจากนั้นยังสามารถมองเห็นหลอดเลือดดำตับได้ชัดเจนถึง 85.2% ซึ่งในรายที่เห็นหลอดเลือดดำตับได้ชัดเจน สามารถพบหลอดเลือดดำที่มีความสำคัญต่อการผ่าตัดได้แก่ accessory right hepatic vein และ segment VIII vein ที่มีขนาด ≥ 5 มม. ได้ถึง 93.8% และ 100% ตามลำดับ*

สรุป: *การตรวจหลอดเลือดตับด้วยเครื่องเอกซเรย์คอมพิวเตอร์มีประสิทธิภาพดีเยี่ยมสำหรับใช้เป็นการตรวจเพื่อวางแผนการผ่าตัดบริจาคตับ*