Multislice Ct in the Evaluation of Potential Living Donors for Liver Transplantation

Osama Mohamed Ebied (MD)[1], Waleed Abd el Fattah Mousa (MD)[1], Mohamed Mohamed Houseni (MD)[2] and Dina Metwaly Barseem (M.B. B.Ch.)[2]

[1]Radiology Department, Faculty of Medicine, Menoufia University, Egypt
[2] Radiology & interventional Department, National Liver Institute, Menoufia University, Egypt
hamza_said_2000@yahoo.com, d.rezk1980@yahoo.com

Abstract: **Objective:** to determine the role of Multislice CT as a possible tool in evaluation of potential cases of living liver donors for liver transplantation before surgical interference. **Background:** Multislice CT provides comprehensive and accurate preoperative examination of potential donors undergoing living liver transplantation. That is because of it provide a good data concerning liver parenchyma, all hepatic vasculature including arterial, venous and portal vessels. It also provide a good information about liver volume including total liver, right lobar and left lobar volume. **Patients and Methods:** One hundred out of two hundred and ten consecutive potential donors had sufficient data & MSCT films selected from national liver institute. All donors underwent multi-slice CT of the abdomen and Imaging was performed as part of preoperative workup for potential living-donor liver transplantation. **Results:** Of the 100 patients evaluated by MDCT, about 92 (92 %) are accepted. Eight patients (8%) were excluded from surgery because of Parenchymal & anatomical criteria based on CT findings. Diffuse fatty infiltration in two exclusion (2%), Portal vein variants that precluded surgery resulted in one exclusions (1%) and insufficient liver volume resulted in five exclusions (5 %). **Conclusion:** Multislice CT provides important information in evaluation of potential living donors for liver transplantation.

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I. Introduction

Living donor liver transplantation is increasingly being used to help compensate for the increasing shortage of cadaveric liver grafts. However, the extreme variability of the hepatic vascular systems can impede this surgical procedure. (1)

The first adult-to-adult living donor liver transplant (LDLT) was performed in Hong Kong in 1993. Five years later, the first LDLT was performed in the United States, and, today, there are over 90 centers that perform LDLT across the country, though most are done in a smaller number of larger volume centers. The majority of LDLT done in the United States are for adults using right lobe grafts. As opposed to a left hepatectomy, this procedure provides the recipient with sufficient hepatic mass to replace the cirrhotic liver while still leaving the donor with enough functioning hepatocytes. (2)

The major advantage of living donor liver transplantation is that it increases the number of organs available for transplantation. In addition, living donor liver transplantation allows performance of surgery on an elective basis and frees the recipient from awaiting the availability of a cadaveric organ. These factors may reduce morbidity, mortality, and cost. The reduction in cold ischemia time (the time an ex vivo organ is not perfused with blood) and the use of healthy donor livers are additional advantages of living donor liver transplantation. (3)

Multidetector CT is the most important tool in the assessment of potential donors. MDCT can precisely depict congenital variants, if present, that can influence the surgical technique, identify focal lesions (hemangiomas, focal nodular hyperplasia, adenomas) or diffuse liver diseases (steatosis, hemochromatosis), and calculate the volume of the two liver lobes (4)

The vascular anatomy was evaluated, with special attention given to the origin and course of the artery to segment IV and the presence of variants, especially those considered relative or absolute contraindications for donation, those requiring reconstruction, or those potentially altering the surgical approach. In addition, graft and remnant liver volumes were determined and the liver parenchyma evaluated. Since the safety of volunteer living donors in LDLT has always been considered paramount, evaluation of potential candidates plays a crucial role to confirm suitability and to identify possible contraindications. Each transplant center has its own protocol for living donor evaluation, which typically includes a comprehensive medical and psychosocial examination as well as noninvasive imaging and other studies to assess size, anatomy and function of the liver. (5)

Imaging in a living liver donor has three objectives: (1) To identify any intra-parenchymal lesions or abnormalities like fatty changes. (2) To visualize the extra- and intra-hepatic vascular and biliary anatomy. (3) To determine the size of the whole liver and calculate the graft and remnant liver volumes. The main advantage of CT over MRI is based on a higher spatial resolution and manifold post-processing possibilities. (6)

Potential donors must be healthy volunteers between the ages of 18 and 55 yr. Donors should have normal liver function and no medical comorbidities. Liver biopsy, although not mandatory, is recommended to ensure that there is no occult hepatic pathology and to establish the degree of steatosis. The donor's absolute age is less important than physiologic age. Older donors, however, do have an increased risk of occult medical problems. There is also the concern that livers from older donors will have diminished regenerative capacity, which can affect both recipient and donor outcomes. (7)

Aim of the project:

Aim of this project is to determine the role of Multislice CT as a possible tool in evaluation of potential cases of living liver donors for liver transplantation before surgical interference.

2. Patients and Methods

The current study was performed in the National Liver Institute in the period between October 2008 and January 2014(2008-2013=retrospective study, 2013-2014=prospective study). One hundred out of two hundred and ten consecutive potential donors had sufficient data & MSCT films. All donors underwent multi-slice CT of the liver and Imaging was performed as part of preoperative workup for potential living-donor liver transplantation. There were 64 men and 36 women with an age range of 19 to 47 years old (mean 33 years).

Technique:

CT was performed with a Siemens Somatome Definition scanner (20 detectors) at the national liver institute, Menoufia University, Egypt

Patient laboratory data was initially revised with particular interest in the results of the renal function tests (creatinine level & clearance).

Patient was instructed to fast for food for six to eight hours prior to examination and asked to continue adequate simple water intake up to 3 hours prior to examination to ensure adequate hydration and to fill the stomach and bowel by water (which is used as a negative contrast) and to help proper subtraction techniques and visualization of the target vessels.

Patients were taught how to hold breath during examination when requested, to ensure their cooperation.

Patients were positioned supine on the CT table in the "head first" position with his arms resting comfortably above the head.

An 18-20 gauge cannula was placed into a superficial vein within the antecubital fossa, or dorsum of the hand.

Before the contrast material was administrated by the injector, saline injections were manually administrated at a high rate of flow, with the patient's arms in the scanning position. This was done to ensure the successful cannulation of the vein.

One scout was acquired in anteroposterior view. The examination is planned on these scouts from the level of the top of the right diaphragmatic copula (Hepatic Dome) till 20 cm caudally in precontrast and post contrast sequences.

A predetermined time delay of average 20 seconds is used for the start of post contrast scanning as regarding that all of the donors are of average weight and circulatory functions as determined from the preliminary first step of preparation.

The precontrast series is taken by using a 10mm nominal section thickness, a slice pitch of 1.5 a gantry rotation period 0.6 second and a table speed of 15 mm per rotation. X –ray tube voltage was 120 KV, and the current was 240-280 mA.

CT angiography was performed following target injection of double his weight by the maximum of 180 ml of contrast medium at a flow rate 5 ml/sec. The contrast medium used was low osmolar non-ionic contrast medium (Ultravist 300)

Arterial dominant phase images were acquired at 18 sec (collimation, 1.25 mm; pitch 0.6 ; kVp, 120; mA, 240–280). Images were obtained from a level 2 cm below the dome of the diaphragm to 2 cm below the origin of the superior mesenteric artery.

Portal dominant phase images were acquired at 60 sec (collimation, 2.5 mm; pitch 0.6; kVp, 120; mA, 240–280). Images were obtained through the entire liver.

Delayed phase images also then taken through the entire liver and were acquired at 200 sec (collimation, 2.5 mm; pitch 0.6; kVp, 120; mA, 240–280).

Then images were reconstructed at 1.5 collimation and 0.7 position increment.

Image Processing

Axial images were reconstructed with a standard algorithm, and post-processing was performed on a commercially available workstation (Song work station).

Major vessels were visualized with volume rendering (VR) and shaded-surface display (SSD). Three-dimensional models of the vascular structures were also generated, and visual enhancement was achieved by artificial color assignment of the vascular models.

Total liver volume was measured by hand tracing the liver outline on the axial portal venous phase images. The following volumes were calculated: Total liver volume, Right lobe with middle hepatic vein, right lobe without middle hepatic vein, left lobe with hepatic vein and left lobe without hepatic vein. And then the volume of the planned graft was correlated with the weight of the recipient and donor to make sure that the graft and remaining part was adequate for recipient and donor respectively. The equation used for this is GRWR.

(Graft weight /Recipient weight ratio) and the result must be 1 %.

Image Interpretation

All axial images were evaluated to assess hepatic morphology for evidence of fatty infiltration and the presence of incidental liver lesions.

The native attenuation value of normal liver on unenhanced CT typically measures between 45 and 65 HU, and is generally at least 8 HU higher than the spleen. In patients with fatty change, however, liver parenchymal attenuation is reduced, typically 10 HU less than the spleen on unenhanced CT and 25 HU less than the spleen on enhanced CT. Because the relative densities of liver and spleen are variable on enhanced CT scans, the diagnosis of hepatic steatosis is more reliably made on nonenhanced images.

As for the hepatic vasculature, the technique was considered technically adequate if there was visualization of the vascular structures in all phases sufficient to permit image reconstruction. Arterial phase images should allow complete opacification of tertiary order branches, particularly the artery to segment IV. Portal and venous phase images should allow complete opacification of the small vessels (less than 3 mm), particularly accessory inferior right hepatic veins.

The resulting two-dimensional reformations and 3D models of the hepatic arteries, hepatic veins, and portal veins were also evaluated. In all cases, reconstructed models were carefully reviewed and compared with the axial source images to ensure that no important vascular structures were inadvertently deleted from the vascular model.

Electronic calipers were used to provide distances between important vascular structures. If the artery to segment IV arose from the right hepatic artery, the distance between its origin and the origin of the right hepatic artery was measured. If an accessory inferior right hepatic vein was identified, its size and the distance between it and the right hepatic vein were measured in the coronal plane.

Each study was evaluated for possible exclusion criteria, such as variants in the portal venous anatomy that preclude surgery, fatty infiltration of the liver, and insufficient liver volume both to leave behind in the healthy donor and to sustain metabolic function in the recipient.

Image Display

All images, including 3D reconstructed models, were sent to (Song work station) workstation which found in National Liver Institute and permits interactive analysis., and were copied on hard copies.

3. Results

In our study The donors include 64 males (64 %) and 36 females (36 %), their ages ranging from 19-47 years old with mean age 32 years old. These data are classified according to age and sex as seen in (Table 1)

Of all 100 patients examined, two donors (2%) had evidence of diffuse fatty infiltration and were excluded from surgery after confirmation by liver biopsy. These potential donors had liver attenuation measuring below 20-30 HU. Other liver lesions include small hemangioma seen in (one donor) Area of hepatic arterial attenuation difference (post biopsy) (3 donors), Focal Fatty Infiltration (one donor) & Cyst (one donor) none of them were excluded. (Table 2)

Seventy nine donors (79%) showed standard anatomy where the common hepatic artery arose from the celiac trunk and divided into RHA and LHA. In sixteen donors (16%), the RHA arose from SMA (replaced RHA); while in only one donor (1%) the accessory LHA arose from LGA. In four Donors (4%), there was an accessory RHA arose from SMV. No other anatomical variations of hepatic artery could be detected in the examined donors. (Table 3)

Seventy nine Donors (79%) showed standard anatomy where the portal trunk divides in the liver hilum into two branches: the left portal vein branch and the right portal vein branch, The right portal vein branch divides secondarily into two branches: the right anterior portal vein feeding segments V and VIII and the right posterior vein feeding segments VI and VII, nine (9%) of whom had a trifurcation, eleven donors (11%) of whom had the anterior branch arose from LPV and the remaining donor(1%) of these donors had a PV quadrifurcation. (Table 3)

Most of donors seventy two (72%) had standard anatomy of hepatic veins which is three main hepatic veins. The right hepatic vein (RHV) is often the largest of the three and drains the greatest part of the right lobe. The middle hepatic vein (MHV) drains the central sector of the liver (segments IV, V, and VIII), and its branching and confluence pattern is quite variable. The MHV usually joins the left hepatic vein (LHV), which drains the LLS (segments II and III), to form a common trunk that empties into the inferior vena cava (IVC). Single accessory right hepatic vein was seen in twenty one Donors (21%), and two or more accessory veins were seen in seven Donors (7%). (Table3)

(Graft weight /Recipient weight ratio) and the result must be 1 %. In five donors only the volume was small for size and those donors were excluded. (Table 2)

Incidental extra-hepatic lesions include renal cysts and gallstones seen in three donors, minimal pelvic fluid collection (post ovulatory versus PID) (one donor) & mildly enlarged spleen seen in two donors. These lesions had no role in patient selection.

(Table 1): Classification of the potential donors according to age and sex

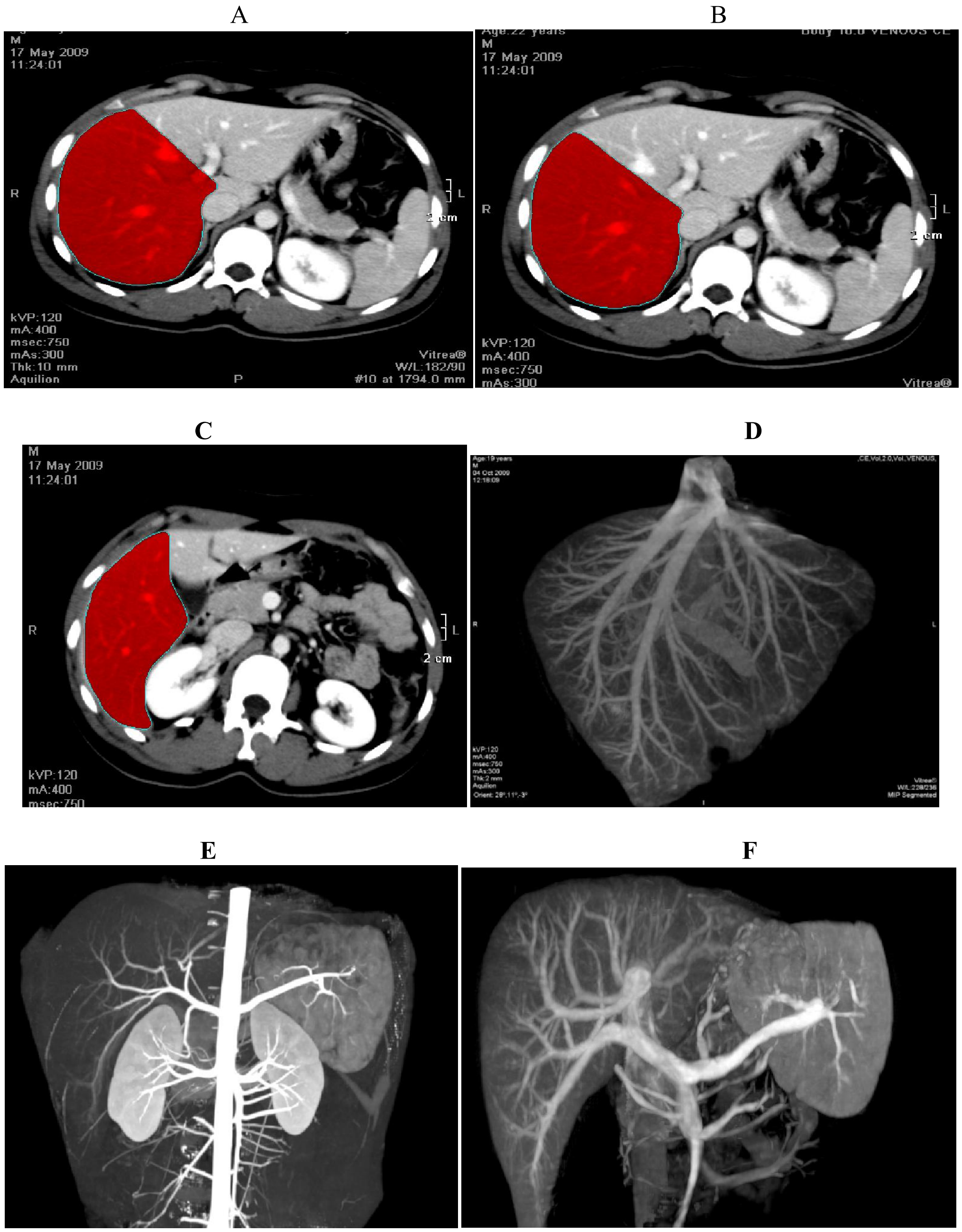
Category	**Age**						**Sex**	
Group	**15-20**	**21-25**	**26-30**	**31-35**	**36-40**	**41-47**	**M**	**F**
Number	15	27	24	17	11	6	66	34
Percentage%	15	27	24	17	11	6	66	34

(Table 2): Classification of the potential donors according to liver parenchymal CT finding & volumetry.

Finding	**Patients**		**Exclusion**
	Number	**%**	
Liver Parenchyma:			
Normal	92	92	No
Area of hepatic arterial attenuation difference(post biopsy)	3	3	No
Focal Fatty Infiltration	1	1	No
Haemangioma	1	1	No
Cyst	1	1	No
Diffuse fatty infiltration	2	2	No
Liver Volume:			
Average For Size	95	95	No
Small For Size	5	5	Yes

(Table 3): Classification of the potential donors according to CT angiography variation with percentage.

Finding	**Patients**		**Exclusion**
	Number	%	
Hepatic arteries (According to Michels Classification):			
Type I (Standard Anatomy)	79	79	No
Type II (Replaced LHA)	--	--	No
Type III (Replaced RHA)	16	16	No
Type IV (Replaced RHA & LHA)	--	--	--
Type V (Accessory LHA From LGA)	1	1	No
Type VI (Accessory RHA From SMA)	4	4	No
Type VII (Accessory RHA & LHA)	--	--	--
Type VIII (Accessory RHA & LHA with replaced RHA or LHA)	--	--	--
Type IX (CHA Replaced to SMA)	--	--	--
Type X (CHA Replaced to LGA)	--	--	--
Hepatic veins:			
Type I Standard	72	72	No
Type II Single accessory right hepatic vein	21	21	No
Type III Two or more accessory right hepatic veins	7	7	No
Portal veins:			
Type I Standard	79	79	No
Type II Trifurcation of main portal	9	9	No
Type III Anterior branch from LPV.	11	11	No
Type IV LPV from Anterior branch	--	--	--
Type V Quadrifurcation of main portal vein	1	1	Yes



Example of case rejected

Age: 21
Sex: Male
Cause of rejection: PV Quadrifurcation.
Multi-slice CT Findings:
* Liver Parenchyma Normal
* Vascular anatomy
-- Hepatic Artery Type I (Standard)
-- Portal vein Type V (Quadrifurcation)
-- Hepatic Veins Type I (Standard)
* Liver Volume
-- Right Lobe with MHV= 757
-- Right Lobe without MHV = 706
-- Left lobe with MHV = 369
-- Left Lobe without MHV =318
-- Total Liver Volume = 1075
* Recipient Body Weight (Kg) = 72
GRWR (if Right Lobe with MHV) = 1.05
GRWR (if Right Lobe without MHV) = 0.98
GRWR (if left Lobe with MHV) = 0.51
GRWR (if left Lobe without MHV) = 0.44
* Incidental Extra-hepatic Findings: No

Figure (1) A-F example of rejected case **A & C**: Volumetry of RT lobe with MHV. **B:** Volumetry of Right lobe without MHV **D:** Hepatic veins Venography (Type I) **E:** Hepatic Artery Angiography (Type I). **F:** Portal Vein Portography (Type V).

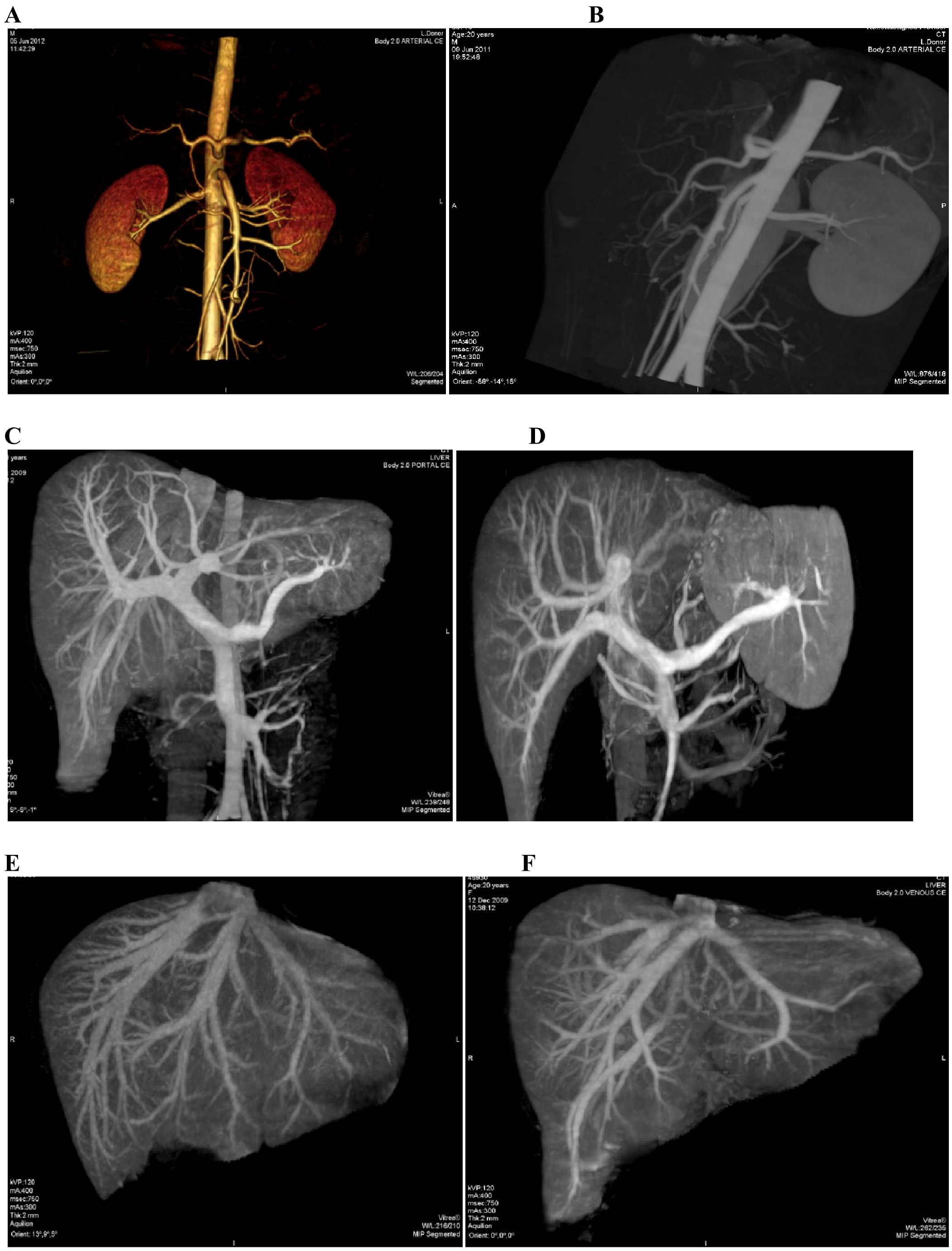


Figure (2) A-F hepatic CT angiography showing the standard anatomy & example of variant
(A) Three-dimensional volume-rendered (VR) image shows the normal hepatic arterial anatomy. CHA (common hepatic artery), GDA (gastroduodenal artery), LHA (left hepatic artery), PHA (proper hepatic artery) and its bifurcation, RHA (right hepatic artery). Michel type I. **(B)** (MIP) image from CT data shows a replaced right hepatic artery RHA arising from the superior mesenteric artery (SMA). Michel type III. **(C)** Normal portal venous anatomy. The left (LPV), main (MPV), and right portal (RPV) vein are well visualized. Superior mesenteric vein (SMV) and splenic vein (SV). Type A. **(D)** (MIP) image from CT data shows portal vein type V (Quadrifurcation of PV). **(E)** Coronal MIP, showing normal hepatic venous anatomy of the same patient with the left hepatic vein (LHV) forms a common trunk with the middle hepatic vein (MHV), whereas a large right hepatic vein (RHV) drains the right lobe independently. **(F)** Coronal MIP, showing type III hepatic vein (more than one accessory inferior right hepatic vein.

4. Discussion

It should be emphasized that the evaluation of the donor must be individualized and should never be performed apart from evaluation of the recipient; it is the combination of characteristics of both the donor and the recipient that helps determine whether the two are suitable for consideration for LDLT. Hence, close cooperation between radiologists and surgeons is mandatory to achieve optimal results.20 Multidetector CT is an excellent tool for mapping out the hepatic vascular anatomy; it is essential that the radiologist be familiar with the normal liver anatomy and be able to recognize the presence of variants, especially those considered relative or absolute contraindications for donation, those requiring reconstruction or multiple anastomoses, and those that may alter the surgical approach. (8)

Although virtually none of the known arterial variants is considered a contraindication for surgery, the hepatic artery is subject to many anatomic variations that may alter the surgical approach. (8)

Several studies have evaluated the relationship between donor age and recipient outcomes. An illustrative report by Hoofnagle *et al.,* 1995 included 772 patients who underwent liver transplantation at three centers. Older donors were defined as those ages 50 and above. In multivariate analysis controlling for donor and recipient factors, reduced graft survival was identified only for older donors when the allograft was rated to be poor or fair in quality by the surgeon at the time of harvest. (9)

However, some studies have demonstrated good outcomes in recipients from elderly donors. (10)

Transplantation of livers from female donors was associated with reduced outcomes in many, but not all series. Some studies suggest that gender mismatched transplants in which the liver from a female donor is given to a male recipient may be particularly problematic. (11)

In our study the donors include 66 males (66 %) and 34 females (34 %), their ages ranging from 19-47 years old with mean age 33 years old.

Assessment of the hepatic arterial anatomy is one of the most important steps in the preoperative evaluation of potential liver donors because hepatic arterial anatomy is extremely variable and some anatomic variations may necessitate modification of the surgical approach. The main goal of presurgical evaluation of the hepatic arterial anatomy is to provide a complete arterial ‘‘road map’’ for the transplantation surgeons. (12)

These variations in HA were detected in different studies and its percentage defers in each study according to number of candidates e.g 30% in the study done by Hasan *et al.,* 2013 (12), 20% by Mohamed *et al.,* 2011 (8), 40% by Schroeder *et al.,* 2006 (13) 30 % and in Kamel *et al.,* 2001 (14). The percentage in our study was 21%.

When normal arterial anatomy is found a hepatic artery with sufficient length for reconstruction is difficult to obtain because only a part of the liver is harvested. Thus, it is important to recognize the proper hepatic artery bifurcation and to measure the length of the RHA (in cases of right lobe donation) or LHA (in cases of LLS donation) before the next bifurcation. Even so, findings such as filiform or redundant arteries may impede arterial reconstruction. (8)

20% of cases involved in various studies performed by researchers Hasan, *et al.,* 2013 (12), Mohamed, *et al.,* 2011 (8) & Kamel, *et al.,* 2001 (14) had portal vein variations. While in the study done by Akgul, *et al.,* 2002 (15) represent 13.8% & 21.4% by Schroeder, *et al.,* 2006 (13). In our study these variations represent (21%) of our cases. Certain variations in portal venous anatomy are accepted but represent difficulty in surgical technique due to two opening anastomosis such as trifurcation of PV which were 10% of all potential donors in our study in comparison 18 % in Hasan, *et al.,* 2013 (12)study. However in the study done by Akgul *et al.,* 2002 (15) they represent 12.3%. While in the study done by Kamel *et al.,* at 2001 (14), they represent 15% and the researchers considered this variation as a contraindication to transplantation.

Other variations are considered as absolute contraindications to surgery, including undivided portal vein. This variation not seen in our study nor in Kamel and his coworkers in 2001 (14), but represent 0.8 % in the study of Torres *et al.,* 2005. (16). Also, quadrifurcation of portal vein trunk, which was seen in one potential donor (2.5%) in Kamel *et al.,*'s study in. 2001(14), and also one potential donor in our study representing 1%. These mentioned variations are considered as absolute contraindications because of when a right hepatectomy is performed, it results in more than one portal vein anastomosis being required, with an increased risk of postoperative portal vein thrombosis in donors.

In our study, preoperative assessment revealed twenty one cases of single accessory vein that represent 21% and seven cases of two or more accessory vessels representing (7%). So, total percentage of presence of accessory hepatic veins was about (28%). Compared to 40% in Guiney *et al.,* 2003 (17) study which applied on the same number of potential donors (about 100) If an inferior right accessory vein is present, its distance from the right hepatic vein was measured in the coronal plane. If the distance between the right hepatic vein and the accessory inferior right hepatic vein is more than 4 cm, it may be difficult to surgically implant both veins with a single partially occluding clamp on the recipient’s inferior vena cava. As mentioned Accessory right inferior hepatic veins were detected in 27 potential donors (67.5%) in Kamel *et al.,* 2001 (14). This inferior right accessory vein when present should be preserved to reduce the risk of graft malfunction, especially if they are larger than 3 mm in maximum diameter. Detection of numbers of accessory hepatic veins is important as their presence can significantly increase operative time.

So by using multi-slice CT, The arteries and veins of the liver are displayed in an anatomic orientation that can be easily evaluated by the surgeon. Branching points to relevant arteries and veins and their relation to the proposed site of incision can be viewed in 3D models and it also important in hepatic resection techniques.

Fatty infiltration in hepatic grafts is known to be an important risk factor for primary graft nonfunction in deceased donor liver transplantation as well as in LDLT. Liver grafts with a mild degree of fatty changes can be used for liver transplantation without ill effect, but liver grafts with moderate or severe degree of fatty changes have been found to have a negative effect on post transplant graft function and patient survival. Marcos et al estimated that 1% of hepatic steatosis can decrease the functional graft mass by 1% (18). More recently the same group published a series in which no impairment in function was found in either the living donor or the recipient using grafts containing less than 30% steatosis. (5)

In our study we were careful to measure homogeneous regions of the liver and bilobar to avoid focal fatty infiltration. Also, density measurements did not include the periphery of the liver consequently, two potential donors (2 %) in our study had diffuse fatty infiltration and were excluded from surgery compared to also four potential donors (10%) in the study of Kamel *et al.,* 2003 (19).

Other liver lesions may also detected with multislice CT examination and its nature demonstrated well due to its contrast enhancement pattern. These lesions may or may not affect the selection of the potential donor according to its nature, For example in our study we detected a single case of focal fatty infiltration (1%) and another case of small haemangioma (1%). Also in three cases (3%) we detect Area of hepatic arterial attenuation difference (post biopsy) of non specific importance. In a similar study by Schroeder *et al.,* in 2006 (13).and another case of small hepatic cyst was detected and not excluded.

Accurate pre-operative assessments of hepatic volumetrics are needed for surgeons to risk stratify and properly select patients for major hepatic resections. (20)

When the donor is being evaluated, lobar and total liver volumes must be known before transplantation. Some transplantation centers estimate the minimum graft volume required to provide sufficient functional hepatocytes to the recipient as follows: graft weight divided by estimated standard liver mass of the recipient (ESLM) and the result must be not less than 40%. (21)

In our study we calculated the suitable graft volume using GRWR not less than 1% and considered any percentage less than that as small-for-size. Our study included five potential donors (5%) where volumetry indicated small-for-size graft and thus had been excluded. In comparison to Kamel *et al.,* 2001 (14) study where three cases (7.5 %) were excluded due to small-for size cause. Different studies have reported excellent agreement between real graft volumes and measured CT volumes (1).

Incidental extra-hepatic lesions could be discovered and evaluated by Multi-slice CT. In our study these lesions included small simple renal cysts, gallstones, minimal pelvic fluid collection (post ovulatory versus PID) & mildly enlarged spleen that were detected in six donors (6%), however these lesions had no role on patient selection. In Schroeder and his coworkers, study in 2006, (13) case of renal mass was detected by CT and the donor was excluded ; laparotomy was done and biopsy was taken from this renal mass and proved to be renal cell carcinoma.

Conclusion

Finally, the result of our study concludes that multislice CT provides comprehensive and accurate preoperative examination of potential donors undergoing living liver transplantation. This information has a major impact on patient selection and allows better planning of a safer surgical approach, which can be expected to reduce postoperative complications.

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