INTRODUCTION

Liver transplantation is the most effective treatment for patients with end-stage hepatic disease ***(Kim et al, 2010).***

Living donor liver transplantation (LDLT) is a complex, innovative surgical procedure, where a donor donates a part of his liver to the recipient, usually the right hemi-liver in adult liver transplants and left hemi-liver in pediatric recipients ***(Vohra et al, 2014).***

The liver volume is one of the most important factors in the selection of appropriate donors. Volumetry of the hepatic graft and remnant is mandatory for LDLT and is usually performed with cross-sectional computed tomography (CT) ***(Nakayama et al, 2006).***

Evaluation of total and segmental liver volumes is crucial because assuring appropriate graft size is one of the major predictors of a safe, successful outcome for both donor and recipient ***(Suzuki et al, 2011).***

A liver remnant measuring 30–40% of the original liver volume is required for the donor to survive. A minimum of 40% of the standard liver mass, which is calculated from body surface area, is needed by the recipient ***(Suzuki et al, 2011).***

Overestimation of the donor's standard liver volume (SLV) may result in excessive hepatic resection leading to liver failure, while underestimation of the recipient's SLV may result in small-for-size graft syndrome ***(Sharma et al, 2016).***

Manual volumetry on CT images is the current "gold-standard" for liver volume calculation. Although manual volumetry can deliver a relatively accurate result, the lengthy and tedious operation, subjective determination, and intraobserver and interobserver disagreement discourage its usage in routine clinical work ***(Cai et al, 2016).***

Volumetry of the liver on CT images is usually performed by manual tracing of the liver boundary and summation of the liver area on each section. However, manual methods require considerable user involvement in the segmentation of the liver on each section, which is a time-consuming process ***(Nakayama et al, 2006)***

With advanced technology, automated computerized liver volumetry may replace manual liver volumetry for accurate calculation of liver volume ***(Cai et al, 2016).***

Our purposes in this study to evaluate automated liver technique for measuring liver volume at CT and to compare its results with those of manual volumetry ***(Suzuki et al, 2011).***

AIM OF THE WORK

The aim of this work is to evaluate the effectiveness and advantages of automated CT volumetry in the assessment of liver volume in living donor liver transplantation and to compare this technique and its results with those calculated from manual volumetry.

Chapter 1

ANATOMY OF THE LIVER

A) Gross anatomy

The liver is the largest organ in the abdomen, occupying most of the right upper quadrant. It varies considerably among individuals in size and configuration. Superiorly, laterally, and anteriorly the liver is bordered by and conforms to the undersurface of the diaphragm ***(Heiken et al., 2006).***

The liver is bordered medially by the stomach, duodenum, and transverse colon, inferiorly by the hepatic flexure of the colon, and posteriorly by the right kidney. The superior portion of the right adrenal gland borders the medial aspect of the posterior superior right hepatic segment (segment VII) ***(Heiken et al., 2006).***

The liver is covered by peritoneum, except for the surfaces apposed to the inferior vena cava (IVC), the gallbladder fossa, and the posterosuperior aspect of the diaphragm (the bare area). It is attached to the diaphragm anterosuperiorly by the falciform ligament and posteriorly by the coronary ligaments. The surface of the liver between the superior and inferior coronary ligaments is devoid of peritoneum and is referred to as the bare area. Because of the lack of peritoneum on this hepatic surface, peritoneal fluid cannot accumulate between the liver and the diaphragm in this area ***(Heiken et al., 2006).***

The liver is enclosed in a thin, fibrous hepatic capsule (of Glisson) that lies just beneath the visceral peritoneum. From the hepatic capsule, septa project inward into hepatic parenchyma ***(Gosling et al., 2002).***

The liver having superior, anterior, right, posterior and inferior surfaces, and has a distinct inferior border. However, superior, anterior, right surfaces are continuous with no definable borders ***(Standring, 2005)***.

B) Hepatic parenchyma

CT has always played a major role in the imaging of the liver, the attenuation value of normal liver parenchyma on unenhanced CT varies considerably among individuals, but generally it is in the range of 45 to 65 HU. In normal adults, the attenuation value of the liver on unenhanced images is consistently higher than that of the spleen, with a mean difference of 8 HU. This hepatic-splenic attenuation difference is due to the high concentration of glycogen within the liver. In unenhanced scans liver veins are seen as tubes of low density than the parenchyma, which reads 50-60HU due to its high glycogen content ***(Heiken et al., 2006).***

The first step in comprehensive preoperative evaluation of potential donors in LDLT is to look for the presence of any unexpected focal liver lesions. Although majority of these lesions are benign, like cysts or hemangiomas, presence of any large lesion or a malignant lesion is a contraindication for organ donation. In addition, donor livers should be evaluated for the presence of fatty infiltration, as increasing hepatic steatosis carries a high risk of postoperative liver dysfunction in donors and graft non-function in recipients ***(Vohra et al., 2014).***

C) Segmental anatomy

Previously the liver was divided into right, left, quadrate and caudate lobes. This has been superseded by the Couinaud system ofliver segments which reflect function as well as gross anatomy ***(Ramachandran and Sohaib, 2012).***

The Couinaud (pronounced "kwee-NO") international classification system divides the liver into eight independent segments (Figures 1 & 2). Each segment is a self-contained unit that can be surgically resected without damaging the remainder of the liver. Each segment has its own dual vascular inflow (hepatic artery and portal vein), its own biliary drainage, and a shared vascular outflow (hepatic veins). The portal triads (bile ducts, hepatic arteries, and portal veins) course through the center of each segment, whereas the hepatic veins define the periphery of the segment and the plane of surgical dissection ***(Brant, 2015).***

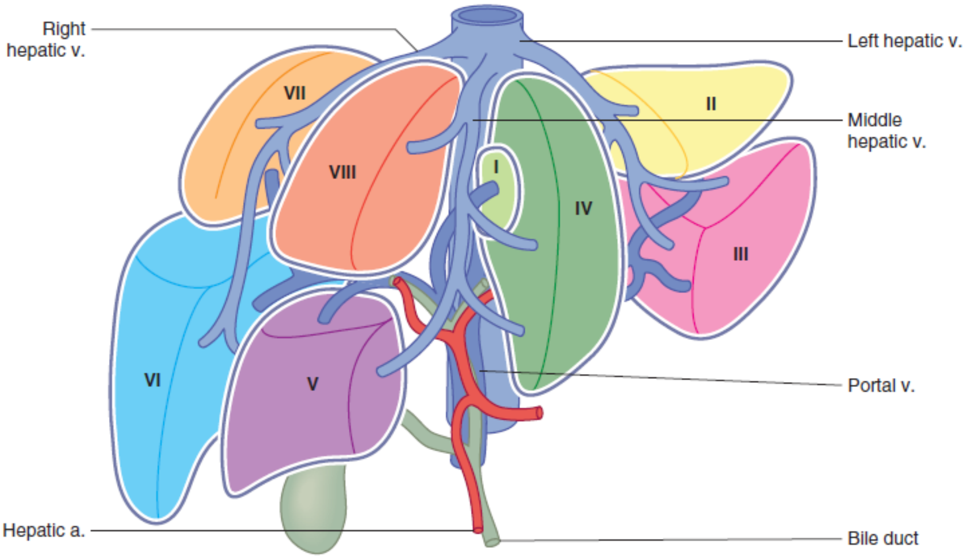

Figure 1. Segmental anatomy according to Couinaud ***(Ramachandran and Sohaib, 2012).***

Division of the liver into eight segments is based on a concept of three vertical planes and one transverse plane.

- A vertical plane through the middle hepatic vein, IVC, and gallbladder fossa divides the liver into right and left lobes.
- A vertical plane through the right hepatic vein divides the right lobe into anterior (VIII and V) and posterior (VII and VI) segments.
- A vertical plane through the left hepatic vein divides the left lobe into medial (IVa and IVb) and lateral (II and III) segments.

- A transverse plane through the left portal vein divides the left lobe into superior (IVa and II) and inferior (IVb and III) segments. An oblique transverse plane through the right portal vein divides the right lobe into superior (VIII and VII) and inferior (V and VI) segments (Table .1.) ***(Brant, 2015).***

Segment I	Caudate lobe
Segment II	Superomedial segment of the left lobe
Segment III	Inferomedial segment of the left lobe
Segment IV	Lateral segment of the left lobe (quadrate lobe)
Segment V	Anteroinferior segment of the right lobe
Segment VI	Posteroinferior segment of the right lobe
Segment VII	Posterosuperiorly segment of the right lobe
Segment VIII	Anterosuperiorly segment of the right lobe

Table 1: Segmental anatomy of the liver ***(Sutton et al., 2003).***

The caudate lobe is connected to the remainder of the right lobe by the caudate process, which can be seen passing between the IVC and the portal vein. A projection of the caudate lobe to the left of the portal vein, called the papillary process of the caudate lobe, may mimic a porta hepatis mass on CT if its continuity with the liver is not appreciated ***(Ryan et al., 2004)***.

The surgical line for right-lobe harvesting in living-donor liver transplantation runs 1 cm right of the middle hepatic vein and parallel to Cantlie's line, and corresponds to a relatively avascular plane. For left lateral segment transplantation, the transection is performed along the main lobar fissure ***(Zamboni et al., 2008).***

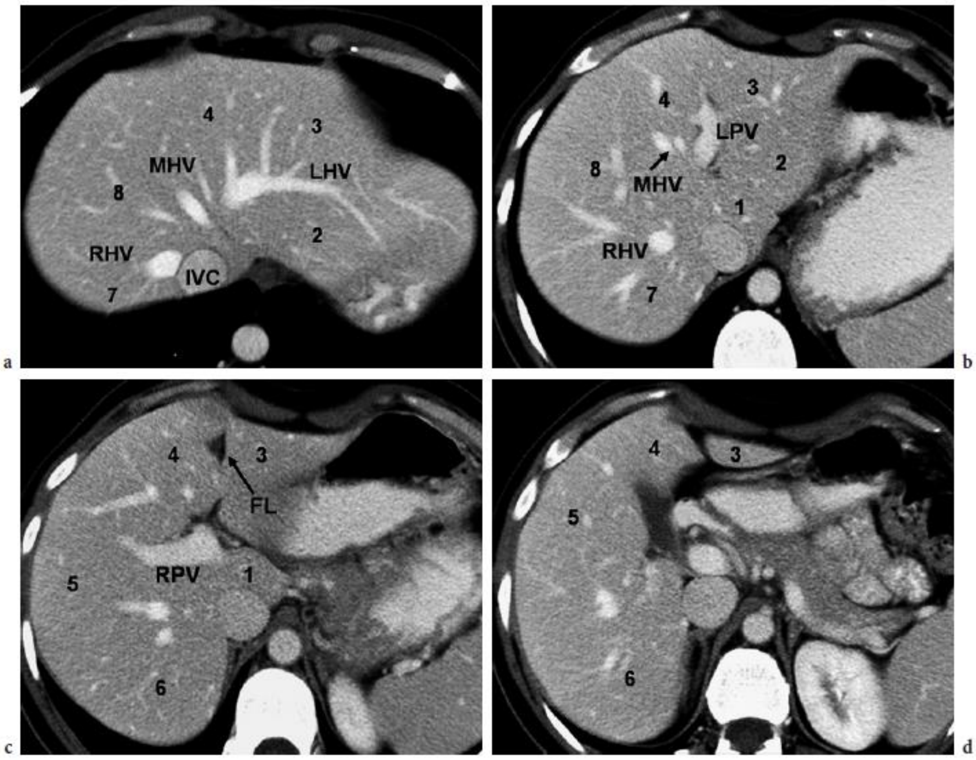

Figure 2. (a–d). CT scan through the liver with Couinaud's segments divided and numbered. RHV, right hepatic vein; MHV, middle hepatic vein; LHV, left hepatic vein; IVC, inferior vena cava; RPV, right portal vein; LPV, left portal vein; FL, falciform ligament ***(Majno et al., 2005).***

D) Vascular anatomy

Knowledge of vascular anatomy of the liver is important, because variant hepatic vascular anatomy can result in modifications or alternative approaches during procedures and surgeries. Evaluation of living liver donors requires careful evaluation of both vascular and biliary anatomy to prevent complications in both donor and recipient ***(Mathew et al., 2018).***

The liver is essential for life and has a rich blood supply. Nearly 20%–25% of the cardiac output (1–2 L/min) goes through the liver. The liver has a unique dual blood supply with oxygen-rich arterial blood from the hepatic artery (HA) and nutrient-rich blood supply from the portal vein (PV) ***(Mathew et al., 2018).***

The PV supply accounts for 70%–80% (90 mL/100 g) from a low-pressure system at 5–8 mmHg, and the HA supplies the remaining 20%– 30% (30 mL/100 g) of blood at high pressure at 60–120 mmHg ***(Mathew et al., 2018).***

Blood from both arterial and portal venous systems mix in the sinusoids that bathe the hepatocytes arranged in cords (Figure 3). From the sinusoids, blood flows into the central veins that drain via the hepatic veins (HV) into inferior vena cava (IVC). At any point of time, about 40% of blood volume in the liver is present in the large vessels and 60% of blood volume in the sinusoids. Blood flow through the liver is a low-pressure perfusion system as blood flows across a large cross-sectional area of the sinusoids ***(Mathew et al., 2018).***

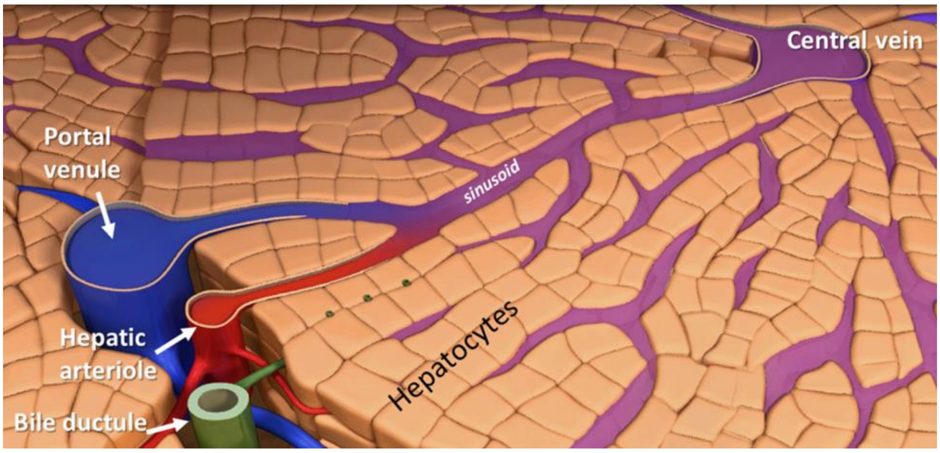

Figure 3. Diagram illustrating vascular supply at the level of the hepatic lobule. The portal vein branch (blue vessel) and the hepatic artery branch (red vessel) from the portal triad supply the sinusoids that lie between cords of hepatocytes. Sinusoids empty into the central vein situated in the center of the lobule ***(Mathew et al., 2018).***

Conventional hepatic arterial anatomy

The conventional arterial supply to the liver (Fig. 4) is by common hepatic artery (CHA) which arises from celiac axis (CA) and divides into the proper hepatic artery (PHA) and the gastroduodenal artery (GDA). The PHA traverses into the liver hilum superiorly and laterally, gives off the left hepatic artery (LHA), and continues as the right hepatic artery (RHA). The RHA splits into anterior and posterior branches that supply the anterior and posterior parts of the right hepatic lobe, respectively. The LHA splits into branches supplying segments

II, III, and IV. Branches from both RHA and LHA supply the caudate lobe ***(Mathew et al., 2018).***

When evaluating a potential right lobe donor, the arterial supply to segment IV must be carefully evaluated, because preservation of the arterial inflow to this segment is fundamental to the prevention of liver failure in the donor. Normally, the artery for segment IV arises from the LHA, but it is not uncommon for the supply to come from the RHA, through an artery that crosses Cantlie's – and therefore the resection – line ***(Zamboni et al., 2008).***

The artery supplying segment IV is called the middle hepatic artery (MHA) (Figure 4). The MHA traverses to the right of the umbilical portion of the left portal vein and it always arises directly or indirectly from the common hepatic artery, from which the gastroduodenal artery also arises. In rare instances of exclusive supply via the RHA, which can occur in 7% of cases, ischemia may be caused if it crosses the surgical plane ***(Mathew et al., 2018).***

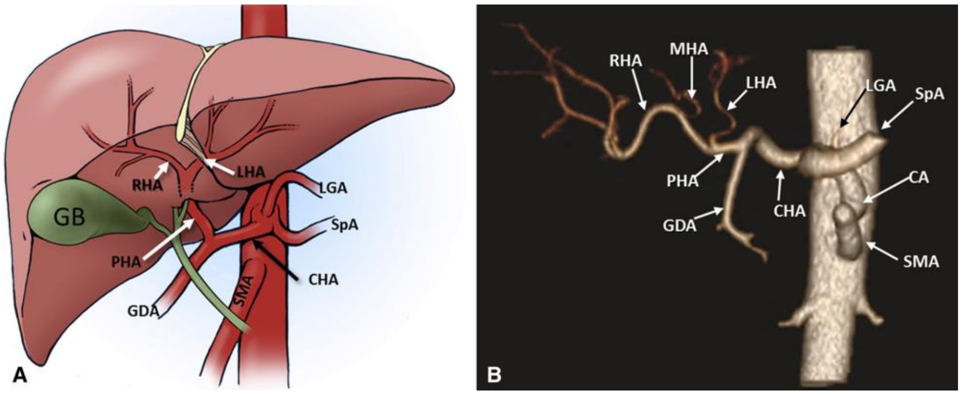

Figure 4. Conventional hepatic artery. Diagram (A) and a 3D volume rendered CTA (B) showing conventional hepatic artery anatomy. Note in the CTA there is middle hepatic artery (MHA) and only a stub of LGA (black arrow) is shown. CA celiac artery; CHA common hepatic artery, SMA superior mesenteric artery, LGA left gastric artery, PHA proper hepatic artery, RHA right hepatic artery; LHA left hepatic artery; MHA middle hepatic artery; GDA gastroduodenal artery; SpA splenic artery; GB gall bladder ***(Mathew et al., 2018).***

Variant hepatic artery anatomy

The variations in the anatomy of the coeliac axis and hepatic artery carry a significant importance in procedures such as transplant of liver, laparoscopic surgery, abdominal radiological interventions and surgical treatment of abdominal injuries (**Yash et al., 2018).**

Michel's' classic autopsy series published in 1966 described the ten basic anatomic variations in hepatic arterial supply and serves as the reference standard (Table 2). Several other variants exist but are not mentioned in the original description, including CHA origin directly off aorta, double hepatic arteries, and PHA replaced to superior mesenteric artery ***(Mathew et al., 2018).***

Michels classification of hepatic arterial anatomy		Frequency of occurrence (%)
I	Normal anatomy: proper hepatic artery originates from common hepatic artery and divides into left and right hepatic arteries	55
II	Replaced left hepatic artery arising from left gastric artery	10
III	Replaced right hepatic artery arising from superior mesenteric artery	11
IV	Replaced left hepatic artery and right hepatic artery	1
V	Accessory left hepatic artery arising from left gastric artery	8
VI	Accessory right hepatic artery arising from superior mesenteric artery	7
VII	Replaced left hepatic artery and right hepatic artery	1
VIII	Replaced right hepatic artery with accessory left hepatic artery or replaced left hepatic artery with accessory right hepatic artery	4
IX	Proper hepatic artery arising from superior mesenteric artery	4.5
X	Proper hepatic artery arising from left gastric artery	0.5

Table 2. Variants of arterial anatomy of the liver according to Michels (1966) ***(Zamboni et al., 2008).***

The type 1 or conventional hepatic arterial anatomy is seen in only about 55%–75% of the population. Therefore, nearly half of the population may have a hepatic arterial variant ***(Mathew et al., 2018).***

The most common variants are the RHA arising from the superior mesenteric artery (SMA) and LHA from the left gastric artery (LGA). These arteries are either replaced or accessory arteries depending on the existing conventional supply from CHA or its branches ***(Mathew et al., 2018).***

A replaced artery is the sole arterial supply to the hepatic lobe whereas accessory is an additional supply to a lobe. Replaced arteries are usually larger than accessory arteries. A replaced hepatic artery usually has longer length and therefore may be easier to anastomose by surgeons ***(Mathew et al., 2018).***

The replaced RHA (rRHA) and accessory RHA (aRHA), and replaced LHA (rLHA) and accessory (aLHA) represent the persistent embryonic supply to the three hepatic lobes, and these arteries would disappear when intrahepatic branches from CHA become the dominant supply to the liver ***(Mathew et al., 2018).***

The variant arteries have predictable courses traversing through fissures (Fig. 5). The rLHA/aLHA traverses through the fissure for the ligamentum venosum, also known as groove of Arantius between the caudate lobe and left lobe posteriorly, and supplies the left lobe. The rRHA/aRHA (Figure 5) originating from SMA traverses posterior to the portal vein and then enters the hilum and supplies the right lobe segments. Identifying an artery in the fissure for ligamentum venosum or posterior to the main portal vein should alert the radiologist for variant arterial anatomy ***(Mathew et al., 2018).***