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Anatomical variations of hepatic artery using the multidetector computed tomography angiography

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Background: *The frequency of normal and aberrant hepatic arteries differs among ethnicities. The aim of our work was to study the frequency of normal and aberrant hepatic arteries among Egyptians using multidetector computed tomography (MDCT) and to compare our prevalence with the prevalence of other nationalities. In addition, the gender differences of such variations were clarified. Moreover, the arterial feeding of hepatic segment IV was determined.*

Materials and methods: *The present study was carried out on 500 patients (409 males and 91 females). Abdominal CT was performed using two MDCT systems, a 64-row, and a 256-slice system.*

Results: *According to Michel's classification, the normal anatomy (type I) was observed in 369 (73.8%) cases, while anomalous hepatic arterial pattern was detected in 131 (26.2%) cases. These anomalies were distributed as follows: type II in 36 (7.2%) cases, type III in 60 (12%) cases, types IV and V in 5 cases for each (1% each), type VI in 14 (2.8%) and types VIII and IX in a single case for each (0.2% each). Neither type VII nor type X was detected. Nine (1.8%) unclassified cases were observed. According to Hiaat's classification, the anomalies were distributed as follows: type II in 41 (8.2%) cases, type III in 74 (14.8%) cases, type IV in 6 (1.2%) cases, type V in a single case (0.2%) and type VI in 2 (0.4%) cases. Finally, 7 (1.4%) unclassified cases were observed. Common hepatic artery (CHA) originated from coeliac trunk in 98% (79.8% males and 18.2% females). It originated from the abdominal aorta in 0.4% and from the superior mesenteric artery (SMA) in 0.4%. It was absent in 1.2%. Right hepatic artery (RHA) originated from the CHA in 86.6% (69.8% males and 16.8% females) and from the SMA in 13.2% (11.8% males and 1.4% females) and from the abdominal aorta in 0.2% (a single male case). Left hepatic artery (LHA) originated from the CHA in 91.2% and from the left gastric artery (LGA) in 8.8%. The most common origin of the segment IV blood supply was the LHA in 60.8%, followed by the RHA in 35%. Less commonly, blood supply derived from the hepatic artery proper (HAP) in 1%. Combined supply derived from RHA and LHA in 0.8%, from the LHA and HAP in 2% and the least encountered was from the RHA and HAP in 0.4%.*

Conclusions: *Hepatic artery variations among Egyptians have a different distribution when compared to such variations among other species. The normal hepatic arterial pattern was observed in 73.8%, while the anomalous was detected in 26.2%. The CHA originated from the coeliac trunk in 98%, the RHA originated from the CHA in 86.6% and the LHA originated from the CHA in 91.2%. The most common arterial supply of the hepatic segment IV is derived from the LHA (60.2%).* (Folia Morphol 2020; 79, 2: 247–254)

Key word: hepatic artery, anatomical variations, multidetector computed tomography

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INTRODUCTION

Knowledge of hepatic vasculature variants is mandatory in laparoscopic surgery, liver transplants, radiological abdominal interventions and penetrating abdominal injuries [16]. Lack of familiarity with such variants can result in insufficient management and predispose patients to inadvertent injury during open surgical procedures or percutaneous intervention [7].

Normally (12–49%), the liver receives its total inflow from the hepatic branch of coeliac trunk [4]. Aberrant hepatic artery refers to a branch that does not arise from coeliac trunk. There are two types of aberrant hepatic artery: accessory and replaced [6]. The accessory hepatic artery is applied when the normal coeliac right hepatic artery (RHA) or left hepatic artery (LHA) is present and there is an additional artery from other sources. The replaced hepatic artery is applied when the normal coeliac RHA or LHA is missing and the replacing artery comes from another source and provides the sole supply to that lobe [6].

Aberrant hepatic arteries can be of major surgical significance in the laparoscopic procedures and operations of gallbladder, liver, upper intestinal tract, and pancreas [19]. Such aberrant arteries can develop a technical problem for infusion treatment and trans-arterial chemoembolisation of neoplasms [19]. Aberrant LHA lies in the hepatogastric ligament and is prone to laceration or ligation causing fatal ischaemic necrosis of left lobe of the liver [1]. In addition, accessory left gastric artery (LGA) arising from aberrant LHA affects the diagnosis and treatment of proximal gastric and distal oesophageal and hand in intra-arterial infusion of chemotherapeutic agents for hepatic neoplasms [17]. Aberrant RHA leads to alteration in the surgical approach and adversely affects the surgical outcome. Injury to aberrant RHA leads to intra- or postoperative bleeding and ischaemia of right lobe of liver [20].

Multi-detector computed tomography (MDCT) angiography is accurate, and reliable in the evaluation of the hepatic artery configuration [22]. It allows faster volume imaging of the whole liver with thinner slices in high spatial resolution within one breath-hold period, when compared with the CT devices with a single detector row [23].

Recognition of the origin of the artery of segment IV is important for donor evaluation for living donor liver transplantation and for the split liver transplantation [12].

We hypothesized that the frequency of normal and aberrant hepatic arteries differs among ethnicities. So, the aim of our work was to study the frequency of normal and aberrant hepatic arteries among Egyptians using MDCT and to compare our prevalence with the prevalence of other nationalities. In addition, the gender differenced were elucidated. Finally, the arterial feeding of hepatic segment IV was determined.

MATERIALS AND METHODS

The present study was carried out on 500 patients (409 males and 91 females). The mean ± standard deviation of their ages was 54.06 ± 11.6 years. The studied patients were referred to the Radiology Department of Cairo University Hospital and underwent abdominal dynamic enhanced MDCT. The data were obtained during the arterial phase.

Exclusion criteria were impaired renal function (creatinine > 1.2 mg/dL), allergy to iodinated contrast media, previous hepatic or major abdominal surgery and all pathological conditions that may modify the vascular anatomy (i.e. parasitic flow in hepatocellular carcinoma) [4].

Permission from the ethics committee was not requested as CT studies followed routine imaging protocols, and written informed consent was obtained from all patients. All procedures were carried out in accordance with the Declaration of Helsinki 1975, revised 2013.

Abdominal CT was performed using two MDCT systems, a 64-row, and a 256-slice system. MDCT coverage extended from the dome of the diaphragm to the inferior margin of the right kidney. Configurations of MDCT system: detector configurations of 64 × 0.625 mm or 256 × 0.5 mm, respectively; section thicknesses of 0.625 or 0.5 mm, respectively; reconstruction intervals of 0.625 or 0.5 mm, respectively; and table speeds of 64 or 256 mm per rotation, respectively.

Dynamic enhanced MDCT images were obtained in a craniocaudal direction during the hepatic arterial, portal venous and equilibrium phases. A dual-head power injector was used to administer a flush of Iopromide (Ultravist; Bayer Schering Pharma, Berlin, Germany) at 370 mg iodine/mL and 30 mL sterile saline (0.9% NaCl). The contrast medium and saline solution were injected at 4 mL/s through an 18-gauge plastic intravenous catheter placed in an antecubital vein.

Hepatic arterial phase imaging delays were 11–20 s after descending aorta enhancement to 150 HU, as measured by an automatic bolus-tracking technique, and portal venous phase inter-imaging delays were 20–30 s after the aortic enhancement. Equilibrium phase images were acquired 180 s after completion of the contrast medium administration.

For the purposes of this study, only the data obtained during the arterial phase were downloaded onto an off-line workstation (ADW 4.3; General Electric Healthcare, Milwaukee, WI, USA) for image post-processing and analysis. We used multiplanar reformation in three spatial planes and three-dimensional reformation using volume rendering and maximum intensity projection. Images were reformatted, analysed and assessed with respect to origination sites and the anatomy of the coeliac axis and their major branches. The anatomies of the coeliac trunk and hepatic arterial system were analysed individually, and anatomical variations recorded. We analysed patterns of aortic origin for the four major arteries: LGA, common hepatic artery (CHA), splenic artery and superior mesenteric artery (SMA) with adherence to our modified definition of coeliac axis and Song's definition of CHA, whereby CHA is defined as an arterial trunk containing gastroduodenal artery and at least one segmental hepatic artery, irrespective of its origin and anatomic course [28].

The anatomical variations of hepatic arterial system were defined according to Michel's [28] and Hiatt's classifications [6] (Table 1).

Table 1. Michel's [14] and Hiatt's [6] classifications

Type	Description
Michel's classification	
I	Normal anatomy
II	Replaced LHA from LGA
III	Replaced RHA from SMA
IV	Replaced RHA and replaced LHA (types II and III coexist)
V	Accessory LHA from LGA
VI	Accessory RHA from SMA
VII	Accessory LHA and accessory RHA (types V and VI coexist)
VIII	Replaced RHA and accessory LHA or replaced LHA and accessory RHA
IX	CHA from SMA
X	CHA from LGA
Hiatt's classification	
I	Normal
II	LHA (replaced or accessory) from LGA
III	RHA (replaced or accessory) from SMA
IV	Replaced or accessory RHA + replaced or accessory LHA (every combination of a double replaced pattern)
V	CHA from SMA
VI	CHA from aorta

CHA — common hepatic artery; LGA — left gastric artery; LHA — left hepatic artery; RHA — right hepatic artery; SMA — superior mesenteric artery

Statistical analysis

The data obtained from the radiological and anatomical studies were recorded and analysed using IBM SPSS advanced statistics version 21 (SPSS Inc., Chicago, IL). Qualitative data were expressed as frequency and percentage of normal and aberrant hepatic arteries. The gender differences in such variations were clarified using the χ^2 test. A p-value < 0.05 was considered significant.

RESULTS

According to Michel's classification, the normal anatomy (type I) was observed in 369 (73.8%) cases, while the anomalous hepatic arterial pattern was detected in 131 (26.2%) cases. The anomalies were distributed as follows: type II in 36 (7.2%) cases, type III in 60 (12%) cases, types IV and V in 5 cases for each (1% each), type VI in 14 (2.8%) cases and types VIII and IX in a single case for each (0.2% each). Neither type VII nor type X was detected. Nine (1.8%) unclassified cases were observed (Table 2, Fig. 1).

According to Hiaat's classification, the anomalies were distributed as follows: type II in 41 (8.2%) cases, type III in 74 (14.8%) cases, type IV in 6 (1.2%) cases, type V in a single (0.2%) case and type VI in 2 (0.4%) cases. Finally, 7 (1.4%) unclassified cases were observed (Table 2).

According to Michel's classification, the unclassified cases were CHA from the aorta, the CHA from the superior mesenteric with the LHA from the coeliac trunk, the RHA from the aorta, the accessory right hepatic from the aorta, absent coeliac trunk (Fig. 2).

The anatomical variation of the origin of the CHA showed normal origin from the coeliac trunk in 98% (79.8% males and 18.2% females). It originated from the abdominal aorta in 0.4% and from the SMA in 0.4%. It was absent in 1.2% of the cases. The anatomical variation of the origin of the RHA was normal origin from CHA in 86.6% (69.8% were males and

Table 2. Frequency of distribution of hepatic artery

Type	Frequency	Per cent
Michel's classification		
I	369	73.8
II	36	7.2
III	60	12.0
IV	5	1.0
V	5	1.0
VI	14	2.8
VII	0	0
VIII	1	0.2
IX	1	0.2
X	0	0
Others	9	1.8
Hiaat's classification		
I	369	73.8
II	41	8.2
III	74	14.8
IV	6	1.2
V	1	0.2
VI	2	0.4
Others	7	1.4
Total	500	100

16.8 % were females), while it originated from SMA in 13.2% (11.8% were males and 1.4% were females) and from abdominal aorta in 0.2% (a single male case). The anatomical variation of the origin of the LHA was the normal origin from the CHA in 91.2%, while it originated from the LGA in 8.8% (Table 3, Figs. 1, 2).

The most common arterial supply of the hepatic segment IV is derived from the LHA (60.2%), followed by the RHA in 35%. Less commonly, blood supply derived from hepatic artery proper (HAP) in 1%. Combined blood supply derived from the LHA and RHA in 0.8%, from the LHA and HAP in 2% and the least encountered was from the RHA and HAP in 0.4% (Table 4).

DISCUSSION

A comparison with other angiographic studies based on Michel's classification [3, 4, 10, 14, 19, 21, 22, 26] and Hiatt's classification [6, 9, 10, 15, 18, 25, 29] was exhibited in Table 5. Our study showed a higher percentage of normal hepatic artery anatomy (73.8%) compared to that of Michel's study (55%) [28]. Most of the radiological investigations displayed percentages near to that found in our study. The

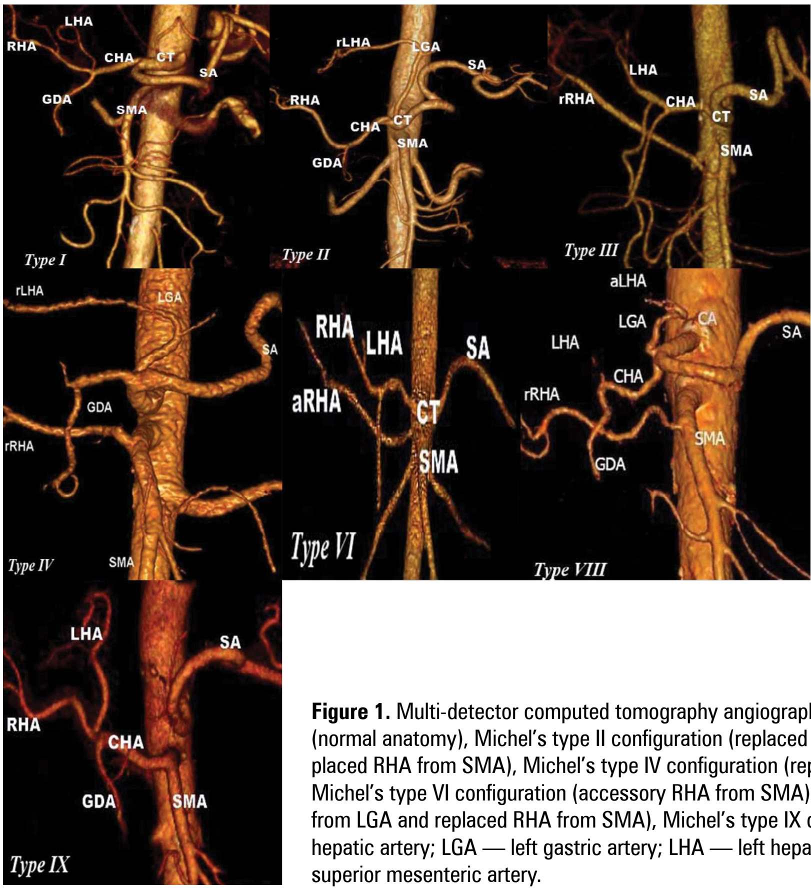

Figure 1. Multi-detector computed tomography angiography images showing Michel's type I configuration (normal anatomy), Michel's type II configuration (replaced LHA from LGA), Michel's type III configuration (replaced RHA from SMA), Michel's type IV configuration (replaced LHA from LGA and replaced RHA from SMA), Michel's type VI configuration (accessory RHA from SMA), Michel's type VIII configuration (accessory LHA from LGA and replaced RHA from SMA), Michel's type IX configuration (CHA from SMA); CHA — common hepatic artery; LGA — left gastric artery; LHA — left hepatic artery; RHA — right hepatic artery; SMA — superior mesenteric artery.

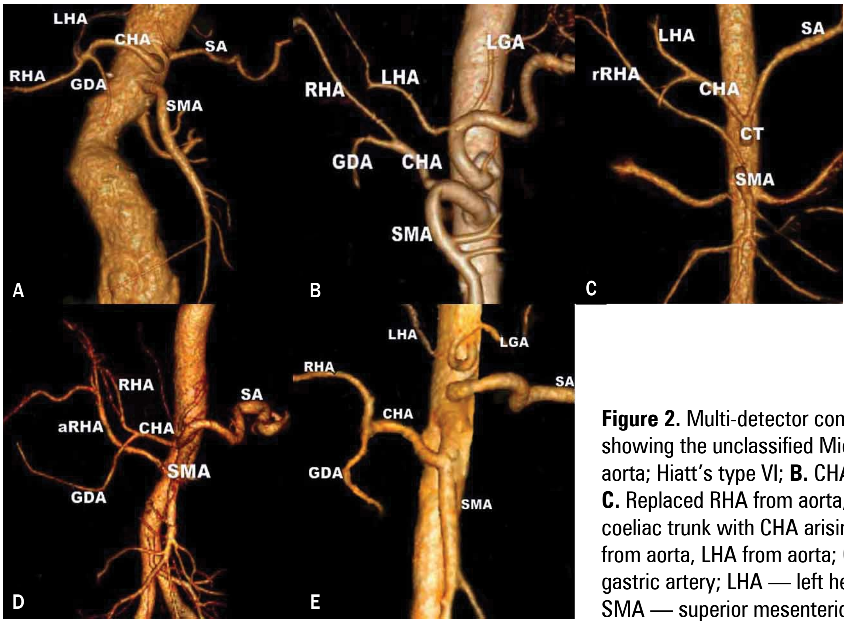

Figure 2. Multi-detector computed tomography angiography images showing the unclassified Michel's anomalies; **A.** CHA arising from aorta; Hiatt's type VI; **B.** CHA arising from SMA and LHA from LGA; **C.** Replaced RHA from aorta; **D.** Accessory RHA from aorta; **E.** Absent coeliac trunk with CHA arising from SMA, splenic artery and LGA arise from aorta, LHA from aorta; CHA — common hepatic artery; LGA — left gastric artery; LHA — left hepatic artery; RHA — right hepatic artery; SMA — superior mesenteric artery.

Table 3. Frequency of origin of the right hepatic artery (RHA) and left hepatic artery (LHA)

Gender		Origin of the RHA			P
		CHA	SMA	AA	
Male	Count	349	59	1	0.2*
	Within RHA	80.6%	89.4%	100.0%	
	Total	69.8%	11.8%	0.2%	
Female	Count	84	7	0	
	Within RHA	19.4%	10.6%	0.0%	
	Total	16.8%	1.4%	0.0%	
Total	Count	433	66	1	
	Within RHA	100.0%	100.0%	100.0%	
	Total	86.6%	13.2%	0.2%	
Gender		**Origin of the LHA**			**P**
		CHA	**LGA**		
Male	Count	374	35		0.3*
	Within LHA	82.0%	79.5%		
	Total	74.8%	7.0%		
Female	Count	82	9		
	Within LHA	18.0%	20.5%		
	Total	16.4%	1.8%		
Total	Count	456	44		
	Within LHA	100.0%	100.0%		
	Total	91.2%	8.8%		

*Statistically insignificant using the Chi-square tests; AA — abdominal aorta; CHA — common hepatic artery; LGA — left gastric artery; SMA — superior mesenteric artery

Table 4. Frequency of arterial supply of segment IV

Arterial supply of segment IV	Frequency	Per cent
LHA	304	60.8%
RHA	175	35%
HAP	5	1%
LHA+RHA	4	0.8%
LHA+HAP	10	2%
RHA+HAP	2	0.4%
LHA+RHA+HAP	0	0%

LHA — left hepatic artery; RHA — right hepatic artery; HAP — hepatic artery proper

anatomical variations in our study were low (26.2%) compared to the variations reported by Michel's (45%), Saba's (38.63%) and De Cecco's (34%) [4, 22, 28]. Many researchers exhibited percentages like that found in our study (Table 5).

The most common anatomical variants observed in our study was the replaced RHA arising from SMA (Michel's type III). It constituted 12% of our studied cases which was in accordance with the findings of Michel (11%), Rygaard (13.4%), De Cecco et al. (9.2%), Saba and Mallarini (10.56%) [4, 21, 22, 28]. A low percentage of this variation was found in the studies of Daly et al. (6%) [3], Chen et al. (5.2%) [2], Stemmler et al. (6.3%) [26]. The replaced RHA is a beneficial variant in right hepatic lobe living donors transplant, as the common postoperative complication in liver transplantation is hepatic artery thrombosis because of shorter and thinner hepatic artery graft. However, the replaced RHA in such cases provides a longer and larger graft, thus reducing chances of hepatic artery thrombosis [13].

Table 5. Comparison with other angiographic studies based on Michel's and Hiatt's classification

	Type	Current series	Michel's, 1966 [14]	Koops et al., 2004 [10]	Saba and Mallarini, 2011 [22]	De Cecco et al., 2009 [4]	Stemmler et al., 2004 [26]	Chen et al., 1998 [2]	Daly et al., 1984 [3]	Rygaard et al., 1986 [21]
Comparison based on Michel's classification	I	73.8	55	79.1	61.37	66	80.9	80.3	76	75.5
	II	7.2	10	2.5	7.48	5.2	0	7.8	4	4.6
	III	12.0	11	8.6	10.56	9.2	6.3	5.2	6	13.4
	IV	1.0	1	1	1.35	2	0	0.7	0	0.9
	V	1.0	8	0.5	6.69	5.2	7.9	1.3	3.5	0
	VI	2.8	7	3.3	6.99	4	0	1.5	4	0
	VII	0	1	0.2	0.73	2	1.6	0.5	0	0.5
	VIII	0.2	2	0.2	1.9	0.6	1.6	0	0	0.5
	IX	0.2	4.5	2.8	1.59	2	1.6	1.6	2	1.4
	X	0	0.5	0	0.31	0	0	0	0	0
	Others	1.8	0	1.8	.09	3.3	0	1.1	6	0
	Total [%]	100	100	100	100	100	100	100	100	100
	Type	**Current study**	**Hiatt et al., 1994 [6]**	**Niederhuber and Ensminger, 1983 [18]**	**Kemeny et al., 1986 [9]**	**Koops et al., 2004 [10]**	**Toda et al., 1987 [29]**	**Mortelé et al., 2003 [15]**	**Soin et al., 1996 [25]**	
Comparison based on Hiatt's classification	I	73.8	75.7	73	59	79.1	64.5	76	69.4	
	II	8.2	9.7	10	17	3	12.8	7	14.2	
	III	14.8	10.6	11	18	11.9	9.9	7	8.7	
	IV	1.2	2.3	2	2	1.3	3.2	3	2.7	
	V	0.2	1.5	0	3	2.8	5	3	2.3	
	VI	0.4	0.2	0	0	0.2	0	0	0.2	
	Others	1.4	0	5	1	1.7	4.1	4	2.5	
	Total [%]	100	100	100	100	100	100	100	100	

The second most frequent variation in our study was the replaced LHA arising from the LGA (Michel's type II). It constituted 7.2% of the studied cases which was in accordance with the findings of Michel (10%) [22], Chen et al. (7.8%) [2], Saba and Mallarini (7.48%) [22]. A low percentage of this variation was found in the studies of Daly et al.,1984 (6%) [3], Rygaard et al., 1986 (4.6%) [21], De Cecco et al., 2009 (5.2%) [4], Koops et al., 2004 (2.5%) [10]. Stemmler et al., 2004 [26] reported absence of such variant in their study. Type II and III variants are suitable for the operation, owing to the longer replaced right or left hepatic arteries allowing the surgeon to perform safer anastomosis [17].

The existence of replaced RHA and LHA (Michel's type IV) constituted about (1%) of the studied cases. Most of the radiological investigations displayed percentages like that. Rygaard et al. [21] and Stemmler et al. [26] reported absence of such variant in their studies.

Great difference was observed in the number of accessory hepatic arteries detected (Michel's types V and VI), with low prevalence in most studies including our study. This difference might be due to the small size of the accessory branches, resulting in the general underestimation of these arteries on angiography [10]. Rygaard et al. [21] reported absence of such variants in their study.

The prevalence of the rare unclassified Michel's or Hiatt's anomalies in our study does not differ from those reported in other publications. We observed five variants that are not included in Michel's scheme; CHA from aorta, CHA from superior mesenteric and left hepatic from coeliac trunk, RHA from aorta, accessory right hepatic from aorta, absent coeliac trunk.

Common hepatic artery originated directly from the abdominal aorta in 0.4% of the studied cases. Chen et al., 1998 [2] and Sureka et al., 2013 [27] reported such variant in 0.5% and 0.33%, respectively.

Other researchers found a higher percentage in their studies (1.7%, 1.35%, respectively) [5, 24]. Right and left hepatic arteries originated from the coeliac trunk directly in 0.2% of our cases. Sureka et al., 2013 [27] reported a higher incidence (1%). Right hepatic artery originated directly from the aorta in 0.2% of our cases. Iezzi et al., 2008 [8], Ugurel et al., 2010 [30] and Sureka et al., 2013 [27] reported variable percentage of this variant (0.2%, 0.3%, 1%).

Recognition of the origin of the artery of segment IV is important for donor evaluation for living donor liver transplantation and for the split liver transplantation [12]. Left hepatic artery feeding segment IV occurred in 60.2% of our cases vs. 53% of Lee's and 55.1% in Saba's studies. Right hepatic artery feeding segment IV occurred in 35% of our studied cases vs. 39% of Lee's and (31.25%) in Saba's studies. Finally, double blood supply from left and right hepatic arteries was found in 0.8% while it was 2% in Lee's and 6.3% in Saba's studies [11, 22]. The latter authors also reported triple blood supply from CHA, LHA, and RHA in 0.6% which was not found in our study. If segment IV artery originates from the RHA, the RHA should be clamped after it gives off the segment IV artery [15]. In right lobe transplantation, if the right hepatic arterial origin of the segment IV artery is not detected prior to the surgery and the RHA is clamped as it takes off from the HAP, the left lobe medial segment that remains in the donor will develop ischaemia [15].

CONCLUSIONS

In conclusion, hepatic artery variations among Egyptians have a different distribution when compared to such variations among other species. The normal hepatic arterial pattern was observed in 73.8%, while the anomalous one was detected in 26.2%. The CHA originated from the coeliac trunk in 98%, the RHA originated from the CHA in 86.6% and the LHA originated from the CHA in 91.2%. The most common arterial supply of the hepatic segment IV is derived from the LHA (60.2%).

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