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Original Article

Anatomy Section

Anatomical Variations in the Branching Pattern of Hepatic Segmental Arteries-A Cadaveric Study

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ABSTRACT

Introduction: The hepatic arterial anatomy is variable. Preoperative evaluation of intra-hepatic arterial pattern is relevant for the surgeons during hepatic surgery as well as for the radiologists while doing endovascular interventions like transarterial chemo-embolization, arterial angiogram etc.

Aim: To identify the variable branching pattern of hepatic segmental arteries.

Materials and Methods: Thirty one formalin embalmed adult livers (both male and female) were dissected and cleaned to observe the branches of hepatic artery to the segments in terms of their point of origin. The branching patterns were photographed.

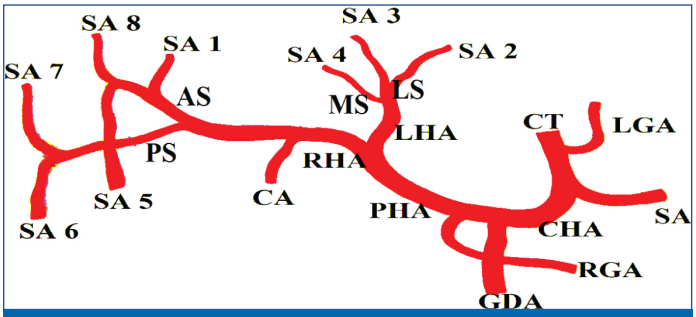
Results: The most common variant arteries were found to be the segment I and IV arteries in terms of their point of origin (71% and 61.3% livers respectively). The origin of other segmental arteries (II, III, V, VI, VII and VIII) were more or less constant. It was also found that segmental arteries can be single or multiple {dual branches were seen for segment I (40%), III (3.2%), IV(19.4%0, VII (3.2%), VIII (12.9%)}.

Conclusion: The variant arterial branching patterns are of great importance in the field of hepatic surgery especially during split and living donor liver transplantations including segmental resection. It will help to reduce the postoperative complications such as hepatic necrosis.

Keywords: Hepatic segments, Liver transplantation, Segmental arteries of liver

INTRODUCTION

Hepatic arterial anatomy is more complex and variable. On the basis of intrahepatic branching patterns of blood supply and biliary drainage, liver creates 8 segmentations (segment I to VIII) [Table/Fig-1]. Usually, proper hepatic artery before entering into liver parenchyma divides into right and left hepatic arteries.



[Table/Fig-1]: Showing extra & intra hepatic arterial pattern.
CT: Coeliac trunk; LGA: Left gastric artery; SA: Splenic artery; CHA: Common hepatic artery; GDA: Gastroduodenal artery; RGA: Right gastric artery, PHA- Proper hepatic artery; RHA: Right hepatic artery; LHA: Left hepatic artery; CA: Cystic artery; AS- Anterior segmental artery, PS: Posterior segmental artery; MS: Medial segmental artery; LS: Lateral segmental artery; SA(1,2,3,4,5,6,7,8)- Segmental artery I, II, III, IV, V, VI, VII & VIII respectively

The right hepatic artery divides into an anterior (supplying liver segments 5 and 8) and a posterior segments (supplying liver segments 6 and 7). The anterior segment often gives a branch to segment 1 (caudate lobe) and to the gallbladder. The left hepatic artery branches into medial segmental artery supplying segment 4 and lateral segmental artery supplying segment 2 and 3 [1].

During 4th week of development, the liver arises from larger cranial part of hepatic diverticulum which develops from the foregut. Liver receives oxygenated blood from umbilical vein during embryogenesis. The amount of oxygenated blood received by the liver through umbilical vein determines the functional hepatic segmentation [2].

Among all the hepatic segments, the segment IV always has been the area of interest in description of segmental anatomy of liver because of a different pattern of blood supply to this segment. The artery to segment IV has been called by many names such as middle hepatic artery, medial segmental artery, artery to quadrate lobe, left medial artery and segment IV artery [3].

Now-a-days the split liver transplantation is an established procedure where there will be splitting of a single donor liver into right (segment V to VIII) and left lobes (segment II and III) [1]. Thereby, two recipients will be benefitted by one single liver. While doing the above mentioned procedure, the surgeons should be aware of the blood supply to segment I and IV because these segments are the intermediate hepatic segments.

Vascular hepatic segmentations are important during segmental resections, partial hepatectomy and liver transplantation procedures. The knowledge of hepatic segmental arterial variation is important for the hepato-biliary surgeons and radiologists to deal with interventional procedures like chemoembolization [4]. Hence, this present study attempts to observe variable branching patterns of segmental arteries to hepatic segments.

MATERIALS AND METHODS

A cadaveric study was done from February, 2013 to February, 2014 in the Department of Anatomy of MS Ramaiah Medical College, BR Ambedkar Medical College, Bangalore Medical College, Sapthagiri Institute of Medical Science, Kempegowda Institute of Medical Science, Bangalore, Karnataka, India. After taking Institutional Ethical Committee clearance, thirty one formalin embalmed livers without any gross abnormality were dissected to observe the intra-hepatic segmental arterial pattern. Standard median vertical incision (extending from xiphi sternum to upper border of pubic symphysis) was given in the anterior abdominal wall. Superficial fascia, muscles and peritoneum were removed to expose the abdominal organs. Abdominal aorta and its branches were cleaned. Further dissection was done to expose the liver. Common hepatic artery was identified. Following this, the liver specimen was removed from the abdominal cavity along with hepatic artery and further cleaned. The soft tissue at the porta-hepatis was dissected to expose the branches of hepatic artery. Finally the segmental branches of hepatic artery were

identified and traced individually to observe the point of origin [5-7]. The main trunk and the segmental arteries were clearly dissected painted by using red Asian paint. The branching pattern of the right and left hepatic artery was traced and accordingly the segmental arteries of liver were identified and looked for presence or absence, number of branches and their point of origin. The findings were recorded and photographed using HD Digital Sony camera (16 megapixel). The variant branching patterns of segmental arteries were documented.

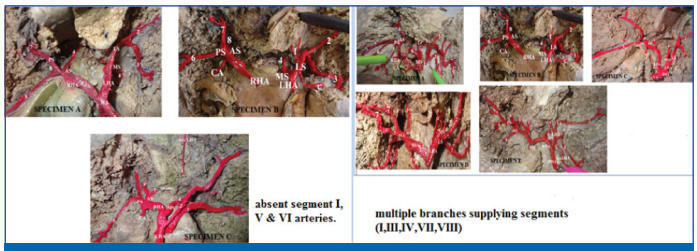
RESULTS

Each segmental artery was traced first to see whether it is present or absent. Then number of branches for each segment and their point of origins were noticed. The findings are mentioned below in forms of tables.

[Table/Fig-2] showing absence or presence of segmental arteries, Segment I artery was absent in 6 specimens segment V artery was absent in 4 specimens and Segment VI artery was missing in 1 specimen [Table/Fig-3].

Segmental artery	No. of specimens showing presence of segmental artery	No. of specimens with absent segmental artery
Segment I artery [Table/Fig-3]	25 (80.6%)	6 (19.4%)
Segment II artery	31 (100%)	0
Segment III artery	31 (100%)	0
Segment IV artery	31 (100%)	0
Segment V artery [Table/Fig-3]	27 (87.1%)	4 (12.9%)
Segment VI artery [Table/Fig-3]	30 (96.8%)	1 (3.2%)
Segment VII artery	31 (100%)	0
Segment VIII artery	31 (100%)	0

[Table/Fig-2]: Showing absence or presence of segmental arteries.



[Table/Fig-3]: Showing absent segmental arteries to I, V and VI and multiple branches to segments (I, III, IV, VII, VIII).

Multiple branches were observed in segment I, III, IV, VII and VIII. So segmental branches of liver are not always single, there can be multiple branches feeding a single segment [Table/Fig-4].

Total No. of specimens with segmental artery	Segmental artery	No. of specimens showing single segmental artery	No. of specimens with multiple segmental artery
25	Segment I artery	15 (60%)	10 (40%)
31	Segment II artery	31(100%)	0
31	Segment III artery	30(96.8%)	1 (3.2%)
31	Segment IV artery	25 (80.6%)	6 (19.4%)
27	Segment V artery	27(100%)	0
30	Segment VI artery	30(100%)	0
31	Segment VII artery	30 (96.8%)	1 (3.2%)
31	Segment VIII artery	27 (87.1%)	4 (12.9%)

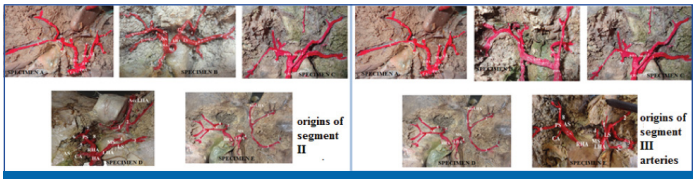
[Table/Fig-4]: Showing single or multiple segmental arteries.
Since the [Table/Fig-4,5] demonstrates the presence of single and multiple segmental arteries and normal/abnormal origin, only those specimen with a presence of segmental artery was considered. Those specimens without a particular segmental artery were not considered for calculation

The variant origins were noticed in all the segmental branches arteries except the origin of Segment VI artery. The Segment I and Segment IV artery were found to be more varied in origin among all other arteries in 72% livers and 61.3% livers respectively. The most common varied artery is Segment I artery according to its presence or absence, number of branches and point of origin [Table/Fig-5].

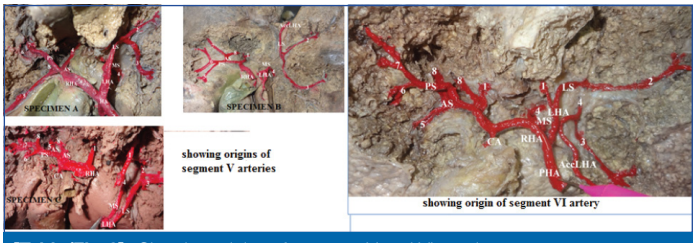
No. of specimen with presence of segmental artery	Segmental artery	Normal origin	No. of specimens with normal origin of segmental artery	No. of specimens with abnormal origin of segmental artery
25	Segment I artery [Table/Fig-6]	RHA	7 (28%)	18 (72%)
31	Segment II artery [Table/Fig-7]	LS branch of LHA	22 (70.9%)	9 (29%)
31	Segment III artery [Table/Fig-7]	LS branch of LHA	23 (74.2%)	8 (25.8%)
31	Segment IV artery [Table/Fig-6]	MS branch of LHA	12 (38.7%)	19 (61.3%)
27	Segment V artery [Table/Fig-8]	AS branch of RHA	19 (70.4%)	8 (29.6%)
30	Segment VI artery [Table/Fig-8]	PS branch of RHA	30 (100%)	0
31	Segment VII artery [Table/Fig-9]	PS branch of RHA	29 (93.5%)	2 (6.5%)
31	Segment VIII artery [Table/Fig-9]	AS branch of RHA	27 (87.1%)	4 (12.9%)

[Table/Fig-5]: Showing origins of segmental arteries.

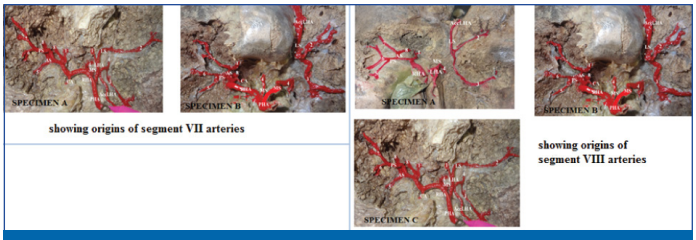
[Table/Fig-6]: Showing origins of segment I and IV arteries.



[Table/Fig-7]: Showing origins of segment II and III.



[Table/Fig-8]: Showing origins of segment V and VI arteries.



[Table/Fig-9]: Showing origins of segment VII and VIII arteries.

[Table/Fig-10] shows that the arteries to segment I and IV showed more variations in origin than normal established pattern. The origin of segment I and IV arteries could be either from RHA or LHA or both RHA and LHA in almost equal proportions. The origins of other segmental arteries are more or less constant. Segment II and III arteries were found to take origin from LHA or branches of LHA and segment V, VI, VII and VIII arteries from RHA or branches of RHA.

S. No.	Segmental Artery	Total Specimen (%)	Normal Origin	Variant Origin								
				PHA	LHA	MS branch of LHA	LS branch of AbLHA	As a continuition of AbLHA	RHA	AS branch of RHA	PS branch of RHA	Dual
1.	Segment I artery	25 (100%)	RHA-7(28%)	2 (8%)	8 (32%)							8 (32%) From both RHA & LHA
2.	Segment II artery	31 (100%)	LS branch of LHA-22 (71%)	2 (6.5%)	--------	1 (3.2%)	4 (12.9%)	2 (6.5%)	--------	--------	---------	---------
3.	Segment III artery	31 (100%)	LS branch of LHA-23 (74.2%)	2 (6.5%)	---------	1 (3.2%)	4 (12.9%)	--------	--------	--------	-------	1 (3.2%) From LS branch & PHA
4.	Segment IV artery	31 (100%)	MS branch of LHA-12 (38.7%)	5 (16.1%)	--------	----------	----------	---------	8 (25.8%)	----------	----------	6 (19.4%) From both RHA & LHA
5.	Segment V artery	27 (100%)	AS branch of RHA-19 (70.4%)	--------	---------	----------	----------	----------	1 (3.7%)	---------	7 (25.9%)	---------
6.	Segment VI artery	30 (100%)	PS branch of RHA-30 (100%)	---------	---------	---------	---------	--------	---------	----------	---------	----------
7.	Segment VII artery	31 (100%)	PS branch of RHA-29 (93.5%)	---------	---------	---------	----------	--------	-------	2 (6.5%)	---------	----------
8.	Segment VIII artery	31 (100%)	AS branch of RHA-27 (87.1%)	---------	---------	---------	----------	----------	1 (3.2%)	---------	---------	3 (9.7%) Directly from RHA or branches of RHA

[Table/Fig-10]: Showing different origins of segmental.
In [Table/Fig-10], Only those specimens showing the presence of segmental artery was considered for calculation of percentages. This [Table/Fig-10] showed the total specimen having segmental artery; So segment I artery was present in 25 specimen out of 31 as shown in [Table/Fig-2]; In the above [Table/Fig-10], the total specimen showing segment I artery is considered 25 (100%)

DISCUSSION

The knowledge of the anatomy of segmental branches of hepatic artery will help in segmental resection of liver. Now-a-days, trans-arterial chemoembolization is the treatment of choice for hepato-cellular carcinoma. For this purpose, micro catheter can be positioned even in segmental branches of hepatic arteries depending on the location and distribution of the lesion [6]. The arterial supply to hepatic segment I and segment IV was found to be more variable. It may be because of their intermediate position in between right and left section of liver.

Segment I Artery

Segment I refers to the caudate lobe of the liver. Normally, Segment I is supplied by a branch arising from RHA (segment I artery). It can also be supplied by multiple small branches arising from the LHA and RHA [8].

Michel NA showed the normal origin of segment I artery from RHA in 35% livers, whereas the most common variant origin was found to be arising from both RHA and LHA [8]. In the present study, the most common variant origin of segment I artery was found to be arising from LHA (32% livers) and from both RHA and LHA (32% livers). It was also arising from PHA in 7% livers which have not been mentioned in the literature [Table/Fig-11].

Origin	Michel NA's [8] study	Present study
RHA (normal)	35%	28%
LHA	12%	32%
RHA & LHA	53%	32%
HA(PHA/CHA)	Nil	8%

[Table/Fig-11]: Comparison of the origin of segment I artery [8].

Gupta CD et.al., divided the caudate lobe (segment I) into caudate lobe proper and caudate process. Caudate process was found to be supplied by RHA in 94.12% livers. The caudate lobe proper was again subdivided into right and left portions. The right portion was supplied by RHA in 60% livers and LHA in 40% livers and the left portion by LHA in 91.77% livers [9]. Kune GA and Segall HN also mentioned the presence of multiple small branches originating from both right and left hepatic arteries supplying caudate lobe [10,11].

The specimens which did not show their regular segment I arteries could be supplied by small branches given off by the adjacent segmental. Moreover, the caudate lobe is located behind all other segments, so it could get blood supply from adjacent segmental arteries. These could be the reason of absent segment I artery.

Segment IV Artery

Normally the segment IV artery is a branch of LHA. It can also be named as artery to quadrate lobe, medial segmental artery or middle hepatic artery [3].

[Table/Fig-12] [3,9,12-14] shows that the most common origin of segmental artery IV to be from either LHA or RHA. HA origin of Segment IV artery was less significant in other studies. The present study showed a similar pattern but the percentage is well distributed among all the four points of origin.

These variations are important during split and living donor liver transplantation. During hemi-hepatectomy, the incision is made across the cantlie's line which is the line connecting the gall bladder and inferior vena cava. So the Segment IV artery arising from right hepatic artery is important in donors as the incision along the cantlie's line can cut the artery. Pre-operative evaluation of artery to segment IV is important to retain hepatic function and avoid ischaemic complication. During right hepatectomy, in patients with RHA type and HA type of origin of segment IV artery, the RHA or HA should be cut distal to the origin of segment IV artery, otherwise it can compromise the blood supply to left lobe of liver [15].

Alghamdi T et al., divided the arterial supply of segment IV in 79.3% liver by a line drawn from left side of inferior vena cava at the top of and lateral to falciform ligament to medial point of gallbladder fossa [16]. Lateral to the above mentioned line, the part of segment IV was supplied by the branches from RHA and the area medial to it by branches of LHA. The middle hepatic artery (artery to segment IV) was originating from RHA (31%), from LHA (31%), from PHA (3.4%) and from both RHA and LHA (3.4%) liver. It was found to be absent in rest 31% livers. These type of variations are important to

Origin	Gupta CD et al., [9] n-85 (%)	Jin Y et al., [3] n-62 (%)	Ahmed A et al., [12] n-1000 (%)	Sureka B et al., [13] n-600 (%)	Onishi H et al., [14] n-125 (%)	Present study n-31 (%)
LHA (normal)	78.82%	32.3%	75%	27.83%	61.5%	38.7%
RHA	4.71%	53.2%	20%	41.33%	27.5%	25.8%
HA (PHA or CHA)	12.94%	4.8%	3.4%	4.5%	NIL	16.12%
Dual (LHA and RHA)	3.53%	9.7%	0%	0%	5.5%	19.4%
Bifurcation of LHA & RHA	NIL	NIL	NIL	NIL	5.5%	NIL

[Table/Fig-12]: Comparison of origin of segment IV artery [3,9,12-14].

know for split-liver resection and ALPPS (associating liver partition and portal vein ligation for staged hepatectomy) procedures. If liver parenchyma is divided with the knowledge of arterial supply of segment IV, then ischaemia, necrosis to segment IV can be prevented [16]. Abdulrasool H et al., also observed the artery to segment IV arise from PHA and RHA [17].

Other Segmental Arteries

Segment II and III Arteries:

Presence or absence: The segment II and III arteries were present in all the specimen [Table/Fig-1].

Multiple segmental branches to Segment II were noticed in one liver specimen.

Point of Origin: The segment II and III arteries take origin from lateral segmental branch of LHA. The segment II and III arteries are also called as lateral superior area artery and lateral inferior area artery respectively [9]. From [Table/Fig-13] it was noticed that the point of origin for both segmental branches (II and III) was from LHA or branches of LHA.

Origin	Segment II Artery		Segment III Artery	
	Present Study N-27(%)	Gupta CD et al., [9] N-85(%)	Present Study N-31(%)	Gupta CD et al., [9] N-85(%)
LS branch of LHA	71%	98.82%	74.2%	98.82%
MS branch of LHA	3.2%	NIL	3.2%	NIL
HA	6.5%	NIL	6.5%	NIL
LS branch of AbLHA	12.9%	NIL	12.9%	NIL
As a continuation of AbLHA	6.5%	NIL	NIL	NIL
LS branch & LHA (Dual)	NIL	NIL	3.2%	NIL
As a continuation of LS branch	NIL	1.18%	NIL	NIL
As a continuation of left vessels in case of double hepatic artery	NIL	NIL	NIL	1.18%

[Table/Fig-13]: Showing comparison of origin of segment II & III arteries [9].

Segment V and VIII Arteries:

Presence or absence: In the present study, the segment V artery was found to be absent in 12.9% (4/31) livers and the segment VIII artery was present in all the specimen (31) [Table/Fig-2]. Multiple segmental branches to Segment VIII were noticed in 4 specimens (12.9%). The branch to segment V was consistently single.

Point of Origin: The segment V and VIII arteries take origin from anterior segmental branch of RHA. The segment V and VIII arteries are also called as anterior inferior area artery and anterior superior area artery respectively [9].

Segment VI and VII Arteries:

Presence or Absence: In the present study, the segment VI artery was found to be absent in 3.2% (1/31) livers and the segment VII artery was present in all the specimen (100%) [Table/Fig-2]. Multiple segmental branches to Segment VII were noticed in 1 specimens (3.2%). The branch to segment VI was consistently single.

Point of Origin: The segment VI and VII arteries take origin from posterior segmental branch of RHA. The segment VI and VII arteries are also called as anterior inferior area artery and anterior superior area artery respectively [9].

From the above [Table/Fig-14], it was observed that arteries to segment V, VI, VII & VIII were originating either from RHA or AS/PS branches of RHA. So it was observed from the present study that most variated arteries are segment I and IV arteries in terms of their point of origin as compared to other segmental arteries because of their intermediate position.

Embryology

Multiple ventral segmental arteries arise from both primitive dorsal aortae at fourth week of development. Most of these ventral segmental arteries disappear. Tenth ventral segmental artery give rise to coeliac trunk. Developmentally, 3 hepatic arteries will be there to supply 3 sectors of liver: 1) left hepatic artery arising from left gastric artery (supplying left sector); 2) middle hepatic artery from coeliac trunk (supplying para-median sector); and 3) right hepatic artery from superior mesenteric artery (supplying right sector). Among these 3 hepatic arteries, only middle hepatic artery persists and ultimately forms proper hepatic artery [18].

In adult, the embryonic para-median sector becomes caudate and quadrate lobes. The embryonic middle hepatic artery supplying the para-median sector give rise to arteries to the caudate and quadrate lobes (segment I and IV). In adult, the proper hepatic artery (embryonic middle hepatic artery) divides into right and left hepatic

Sl. No.	Origin	Segment V Artery		Segment VI Artery		Segment VII Artery		Segment VIII Artery	
		Present Study N-31 (100%)	Gupta CD et al., [9] N-85 (%)	Present Study N-30 (100%)	Gupta CD et al., [9] N-85 (%)	Present Study N-31 (100%)	Gupta CD et al., [9] N-85 (%)	Present Study N-31 (100%)	Gupta CD et al., [9] N-85 (%)
1	AS branch of RHA	70.4%	93.5%	NIL	5.88%	6.5%	NIL	87.1%	91.77%
2	PS branch of RHA	25.9%	4.7%	100%	85.88%	93.5%	100%	NIL	5.88%
3	Directly from RHA	3.7%	NIL	NIL	8.24%	NIL	NIL	3.2%	2.35%
4	Dual	NIL	NIL	NIL	NIL	NIL	NIL	9.7%	NIL

[Table/Fig-14]: Showing comparison origins of segment V, VI, VII & VIII.

artery [3]. Hence, the variant origin of arteries to segment I and IV can be described embryologically. So artery to segment I and IV can take origin either from RHA or LHA or PHA. Being in the intermediate position, the origin of segment I and IV arteries show more variations.

The arterial patterns are not constant as they are formed from diffuse vascular network during the development of cardiovascular system. This could be the reason of variant origins of segmental arteries [9].

Each hepatic segment is independent functionally and in terms of blood supply. But inter-arterial anastomosis can be observed occasionally [1]. Presence of this intra-hepatic anastomotic pattern could be the reason of multiple branches to one hepatic segment. So the surgeons should be aware of multiple branches to hepatic segments.

Clinical Importance

The knowledge of hepatic segmental arteries is of immense importance for the exact identification of each hepatic segment. With this knowledge, radiologists can confirm the location of segmental artery on conventional angiogram or any lesion of segments at CT scan. Liver cancer is very common worldwide. The treatment of choice for hepatocellular carcinoma is trans-arterial chemoembolization [6]. Selective intra-arterial radiation therapy is also done to treat non-resectable hepatic tumours. Selective catheterization is possible with the proper knowledge of hepatic segmental arteries. If trans-arterial chemoembolization is done for a wrong branch without the knowledge of anatomy of hepatic vasculature and its variations, then it can lead to disposition of chemotherapeutic agents in inappropriate hepatic segments [6].

Now-a-days, Living Donor Liver Transplantation (LDLT) is the choice of treatment for end-stage liver disease. If there is injury to hepatic arteries during LDLT, it can lead to hepatic artery thrombosis followed by impairment of adequate blood supply to the retained liver lobe of the donor or graft loss in recipient. Hepatic artery thrombosis commonly involves segment IV artery or middle hepatic artery or artery to quadrate lobe [7]. Functionally quadrate lobe is included to the left lobe of liver [19]. So, there are two important aspects to keep in mind during right lobe LDLT and left lobe LDLT: 1) Preservation of LHA and MHA (artery to quadrate lobe) in the donor to supply the remaining left lobe; and 2) Reconstruction of LHA and MHA to maintain the viability of graft containing left lobe in recipient respectively. It is seen that when LHA gives MHA, then modification of surgery is not needed for the preservation of MHA in right lobe LDLT and for reconstruction of MHA in the graft of recipient in left lobe LDLT. Hence, chances of injury to MHA as well as postoperative hepatic artery thrombosis will be less. But when MHA comes from RHA, then during right lobe LDLT, as right lobe graft includes RHA, so preservation of MHA in donor will be difficult which might reduce the survival rate of left lobe of liver in donor and during left lobe LDLT, the viability of left lobe graft will be poor as RHA (from which MHA was arising) is preserved in donor with right lobe. So when MHA arises from RHA, the chances of MHA injury are high. Therefore liver with presence of accessory hepatic artery would be better for LDLT [7].

LIMITATION

The sample size was small and samples were cadaveric specimens. Identification of sub-segmental branches was beyond the scope of study as the procedure was piece meal dissection. Getting specimen also was difficult for piece meal dissection as the used liver specimen cannot be reused for academic purpose.

CONCLUSION

Intra-hepatic arterial anatomy is variable in branching pattern. It varied in each liver specimen that was dissected. The segment I artery (artery to caudate lobe) and segment IV artery showed variation in terms of their point of origin. Four different points of origin (RHA/ LHA/RHA and LHA/ HA) were observed for the arteries supplying segment I and IV. The knowledge of hepatic arterial branching pattern is must for radiologist to perform different interventional radiological procedures and also important for the surgeons to perform different hepatic surgeries. Blood supply to segment I and segment IV are very essential to know in the hemiliver graft procedure. Further, increasing the sample could give more varied patterns as the sample size was small in the present study.

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