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Arterial liver supply in aspect of right lobe living donor liver transplantation: anatomical variants and reconstruction

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Abstract

Background. *A safe removal of the right lobe liver and restoration of arterial blood supply to the liver graft is possible only with a full understanding of the anatomy of the hepatic artery in a donor.*

Objective. *To describe new and extend contemporary data on anatomical variations of the arterial blood flow in a donor of the right liver lobe.*

Material and methods. *From 2009 to 2021, 306 living donor liver transplantations were performed in the State Research Center – Burnasyan Federal Medical Biophysical Center of Federal Medical Biological Agency. The vascular anatomy of 518 potential donors was analyzed. Hepatic artery anatomical variants of a right lobe graft were assessed.*

Results. *Eleven types of right lobe arterial supply and 7 subtypes of the arterial anatomy of liver segment 4 were identified. The case rates of types and subtypes where reconstruction could be performed were* *following: type A, subtypes 1, 2, 3, 4, 5 (57.5%, 26.1%, 5.5%, 1.9%, 0.3%, respectively); type B, subtypes 1, 4, 5 (0.3% each); type C, subtypes 1, 2 (2.9%, 1.3%, respectively); type D, subtypes 1, 3 (0.3% each); type E subtype 1 (0.6%), types F-J subtype 1 (0.3% each). Right lobe liver harvesting and arterial reconstructions were fully performed in all types and subtypes excluding anatomical type K, subtype 7. Arterial postoperative complications (11 cases) were detected in 3.5% observed cases of 306 transplants and in 5.9% of all patients with complications (184). Mortality rate due to arterial complications was 1.9% (6 cases).*

Conclusion. *The existing classification of the right liver graft hepatic artery anatomy was updated and detailed regarding the applicability in right lobe liver transplant. The arterial anatomy of right lobe liver graft shows great variability and complexity for systematization and thus may need further studies.*

Keywords: living donor liver transplantation, anatomy, hepatic artery, reconstruction, classification

Conflict of interests Authors declare no conflict of interest

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aS4, the artery to the 4th segment of the liver
AsHA, anterior sectoral hepatic artery
CBD, common bile duct
CHA, common hepatic artery
CHD, common hepatic duct
CT, celiac trunk
EVT, endovascular treatment
GDA, gastroduodenal artery
HA, hepatic artery

LHA, left hepatic artery
RLL, right lobe liver
MSCT, multislice spiral computed tomography
PHA, proper hepatic artery
PsHA, posterior sectoral hepatic artery
PV, portal vein
RHA, right hepatic artery
RLLT, right lobe liver transplantation
SMA, superior mesenteric artery

Introduction

Restoration of arterial blood flow in related living donor liver transplantation is an important and complex task of surgical intervention. Technical errors and a number of predisposing factors, such as transarterial chemoembolization and other liver surgeries in the patient medical history, vascular atherosclerosis, multiple arteries and small diameter of arteries create prerequisites for the development of such frequently fatal complication as hepatic artery (HA) thrombosis [1, 2]. The rate of HA complications reaches 2-9% [3]. Mortality from HA thrombosis in related living donor liver transplantation ranges from 3% to 80% [4-8]. Unlike cadaveric liver transplantation, where arterial reconstruction can be performed on larger arterial branches preserved during organ explantation, the arterial reconstruction in related living donor transplantation always involves the use of microsurgical techniques. In addition, an important role is played by understanding the right lobe liver (RLL) arterial supply anatomy. The latter is not as diverse as that of the blood supply to the left lobe, where the presence of two or even three HAs is more common [9]. However, the arterial blood supply to the RLL can also be effected from 2 or even 3 arteries, the trunk of a single HA may be short and have a small diameter; in some cases a branch is observed to originate from the right hepatic artery (RHA) system to the 4th segment of the liver. All of these situations should be considered at the preoperative stage in order to minimize surgical risks for both the donor and the recipient.

The objective was to describe anatomical variants in the arterial blood supply to the right lobe liver in terms of its use in transplantation.

Material and methods

In this paper, we deliberately focused only on classification issues and did not cover in detail the surgical technique features in HA reconstruction, since these aspects of right lobe liver transplantation (RLLT) deserve individual scrupulous consideration. The experience of 306 right lobe liver transplantations in adults from a living related donor performed in 2009–2021 was analyzed. A total of 518 people were examined as potential donors. The anatomical features of the HA structure were assessed at the preoperative stage using multislice spiral computed tomography (MSCT) with intravenous contrast.

A retrospective and prospective study of the HA anatomy was conducted based on MSCT data.

During donor hemihepatectomy after cholecystectomy, the mobilization of the hepatoduodenal ligament elements was performed. The method of HA mobilization also depended on its anatomical features. In most cases, only the RHA was mobilized in the zone syntopically located at the confluence of the lobar hepatic ducts and somewhat more caudally. If necessary, in order to avoid the retrograde thrombi development in the ligated long stump of the HA, its orifice was isolated, and the ligation was performed at no further than 5 mm from it. Devascularization of the common bile duct along its length was also avoided. The portal vein (PV) or its accessible branches were also circularly mobilized in the hepatoduodenal ligament. Before applying vascular clamps to the PV, the blood flow through the HA was limited with a bulldog vascular clamp. The HA was transected with a sharp scalpel first and strictly perpendicular to its axis. The remaining stump of the vessel was ligated [10, 11]. At the “back-table” stage, the HA was washed through a metal cannula by introducing “Custodiol” solution into it at a temperature of 4°C with the addition of heparin in a dilution of 1000 U per 1 liter of solution in a volume of 50 ml. Then, excess periarterial tissues were sparingly excised. Formation of an arterial anastomosis was possible both with separate sutures and with a continuous suture using a binocular loupe with a magnification of x 2.5–3.5, which depended on the surgeon’s preferences. Control ultrasound examinations to assess the blood flow velocity in the graft were performed immediately after the restoration of blood flow in the PV and HA during surgery, then several hours after surgery, then daily during the first week, and then as needed.

The classification is based on the following grouping factors: the site of the artery origin, the syntopy in relation to the PV and bile ducts, the number of arteries supplying the right lobe liver, the relation to the proper HA (PHA), and the place of the artery branch-off to the 4th segment of the liver. The concepts proposed by N. Michels were also used, according to which the arteries supplying the liver and not originating from the PHA are called aberrant, which in turn are divided into the additional ones, functionally duplicating the existing vessels, and the substitute ones supplying blood to certain parts of the liver instead of the usual vessels [12].

Results

A classification of anatomical and topographic types of the RHA structure has been proposed. A total of 11 anatomical types of the artery were identified. Additionally, 7 subtypes of arteries supplying the 4th liver segment were identified. Definitions of the types and subtypes, as well as the possibility of performing reconstruction are given in Table 1. This original classification is shown as MSCT images and reconstructions, schematic Figs. 1–18. The frequency of observing the different types in a series of 306 performed transplants was: type A, subtypes 1–5 (58.4%, 26.1%, 5.5%, 1.9%, 0.3%); type B, subtype 1, 4, 5 (0.3% each); type C, subtypes 1, 2 (2.9%, 1.3%); type D, subtypes 1, 3 (0.3% each); type E, subtype 1 (0.6%); types from F-J, subtype 1 (0.3% each). Each of the identified types was subjected to arterial reconstruction, except for type K registered only in one potential donor who was not suitable for donation for other reasons, and subtype 7, a priori considered unsuitable for donation.

Table 1. Classification of arterial types and subtypes of the donor liver right lobe

Type	Definition	Feasibility of organ harvesting
A	There is a PHA and its bifurcation into the RHA and the left HA (LHA)	+
B	The RHA branches off from the PHA and passes behind the portal vein	+
C	The replaced RHA branches off from the SMA (aorta, celiac trunk (CT), etc.)	+
D	The accessory RHA branches off from the SMA (aorta, CT, etc.), the RHA branches off from the PHA	+
E	Early division of the hepatic duct into the anterior sectoral HA (AsHA) and the posterior sectoral HA (PsHA), the common hepatic duct passing between them	+
F	Trifurcation of the common hepatic artery (CHA) into the gastroduodenal artery (GDA), LHA, and RHA	+
G	Quadrifurcation of the CHA to the GDA, artery to S2, 3, artery to S4, and the RHA	+
H	Fenestration of the RHA, in which the RHA divides into two vessels, circumflexing the common hepatic duct anteriorly and posteriorly, and then merges into a single RHA	+
I	The LHA is absent, the short PHA divides into the artery to S4 and the RHA, which gives off a branch to S8	+
J	PsHA independently branches off from PHA, the early division	+

	of the latter into LHA and AsHA	
K	The right lobe of the liver is supplied with blood by three arteries.	-
Subtype (by artery to S4 of the liver)	**Definition**	**Possibility of organ harvesting**
1	The artery to S4 originates from the RHA	+
2	The artery to S4 originates from the LHA	+
3	The artery to S4 originates from the RHA in close proximity to the site of sectoral branches taking off	+
4	Trifurcation of the RHA: the artery to S4 branches off at the same level as the AsHA and PsHA	+
5	The artery to S4 originates from the AsHA	+
6	The artery to S4 originates from the RHA and LHA	+
7	The AsHA or sectoral HA to S5 or S8 originate from the S4 hepatic artery of the LHA basin	-

Notes: PsHA, posterior sectoral hepatic artery; LHA, left hepatic artery; CHA, common hepatic artery; AsHA, anterior sectoral hepatic artery; CT, celiac trunk

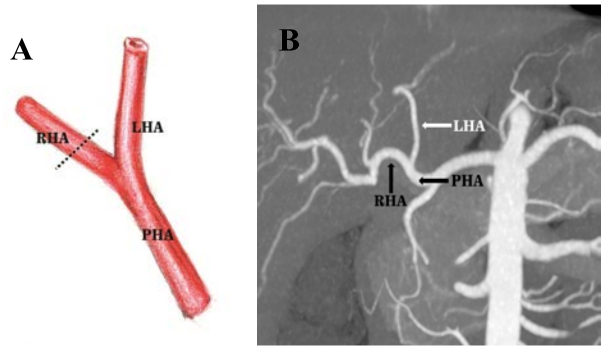

Fig. 1. Anatomical type A. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; PHA, proper hepatic artery; the dotted line indicates the site of the RHA transection

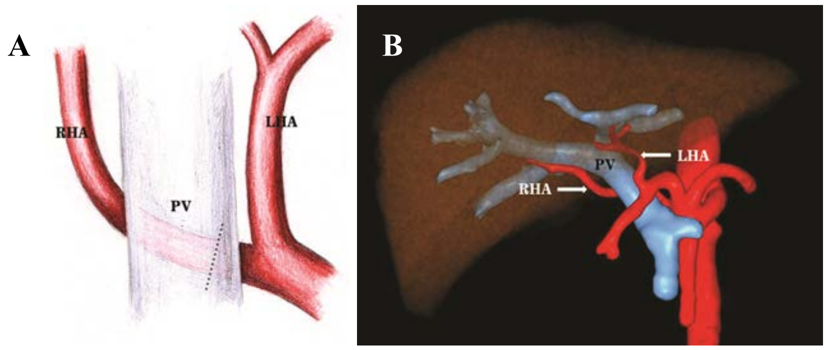

Fig. 2. Anatomical type B. A, diagram; B, reconstruction of multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; PV, portal vein; the dotted line indicates the site of RHA transection

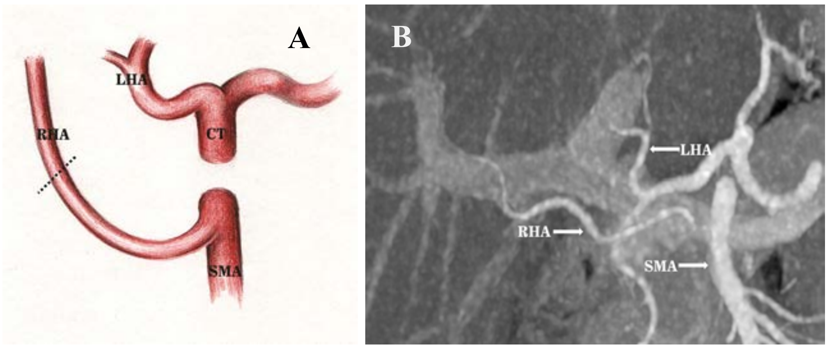

Fig. 3. Anatomical type C. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; CT, celiac trunk; SMA, superior mesenteric artery; the dotted line indicates the site of the RHA transection

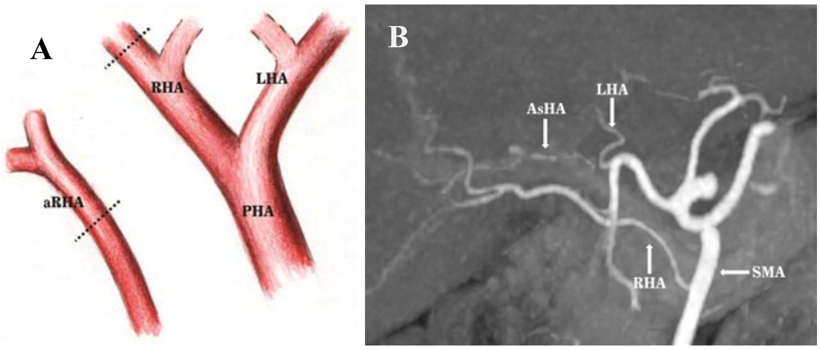

Fig. 4. Anatomical type D. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; ARHA, accessory right hepatic artery, AsHA, anterior sectoral hepatic artery, LHA, left hepatic artery, PHA, proper hepatic artery; SMA, superior mesenteric artery; the dotted line indicates the site of the ARHA

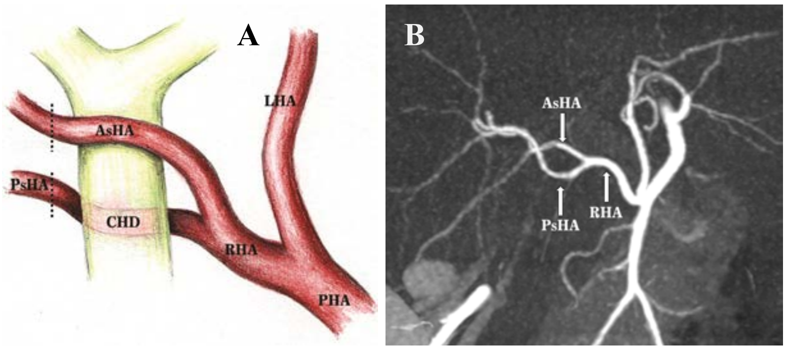

Fig. 5. Anatomical type E. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; AsHA, anterior sectoral hepatic artery; PsHA, posterior sectoral hepatic artery; LHA, left hepatic artery; PHA, proper hepatic artery; CHD, common hepatic duct; the dotted lines indicate the sites of PsHA and AsHA transection

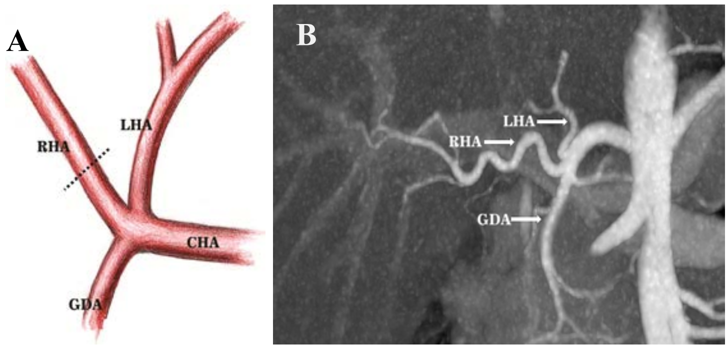

Fig. 6. Anatomical type F. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; GDA; gastroduodenal artery; CHA, common hepatic artery; the dotted line indicates the site of the RHA transection

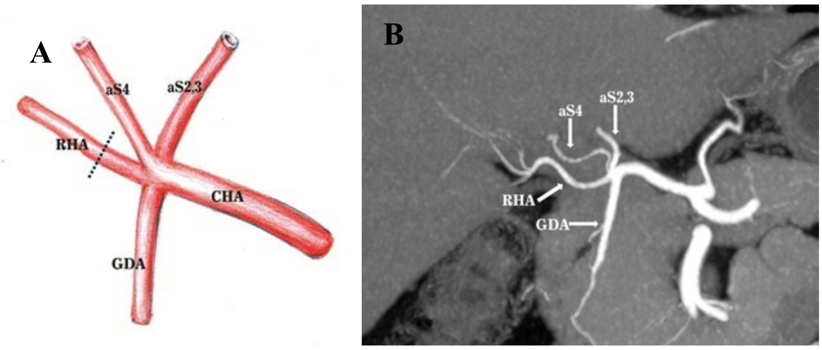

Fig. 7. Anatomical type G. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; GDA, gastroduodenal artery; CHA, common hepatic artery; aS4, the artery to segment 4 of the liver; aS2, 3, the artery to the 2nd, 3rd segments of the liver; the dotted line indicates the site of the RHA transection

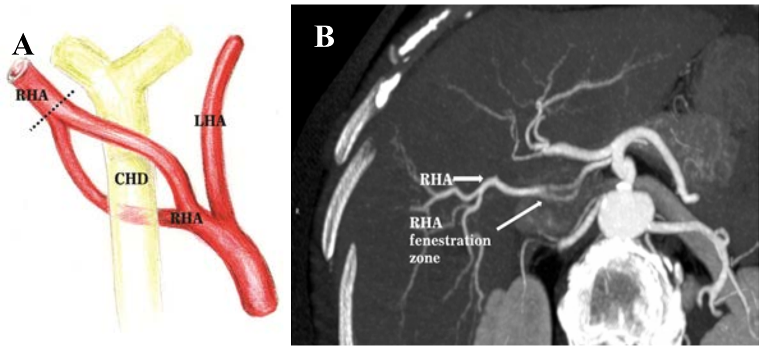

Fig. 8. Anatomical type H. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; CHD, common hepatic duct; the dotted line indicates the site of the RHA transection

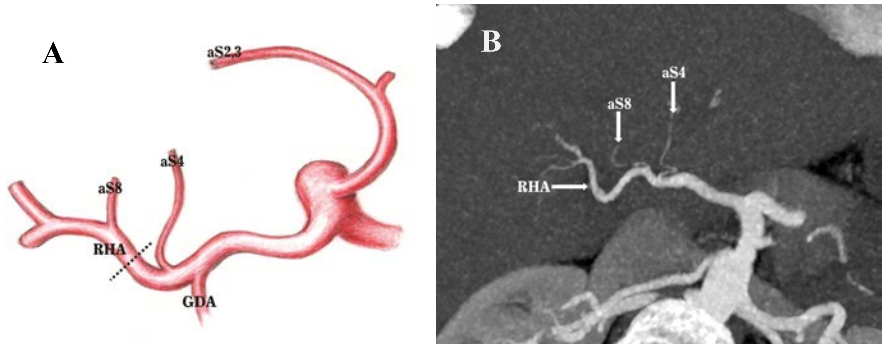

Fig. 9. Anatomical type I. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; GDA, gastroduodenal artery; aS4, the artery to the 4th segment of the liver; aS2, 3, the artery to the 2nd, 3rd segments of the liver; aS8, artery to the 8th segment of the liver; the dotted line indicates the site of the RHA transection

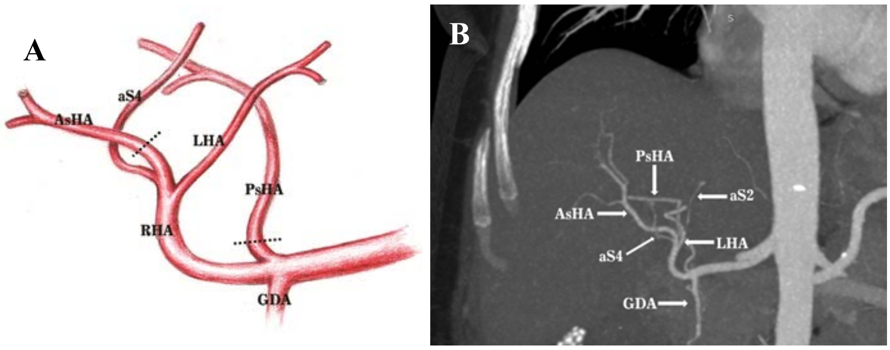

Fig. 10. Anatomical type J. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; GDA, gastroduodenal artery; AsHA, anterior sectoral hepatic artery; PsHA, posterior sectoral hepatic artery; LHA, left hepatic artery; aS4, the artery to the 4th segment of the liver; aS2, the artery to the 2nd segment of the liver; the dotted lines indicate the sites of the AsHA and PsHA transection

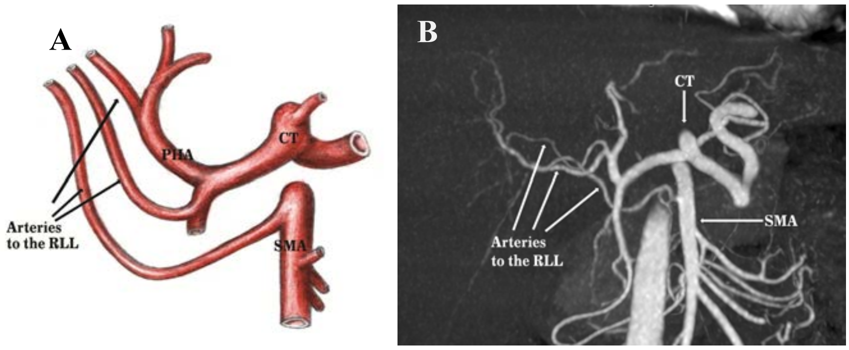

Fig. 11. Anatomical type K. A, diagram; B, multislice spiral computed tomography. LHA, left hepatic artery; PHA, proper hepatic artery; RLL, right lobe liver; SMA, superior mesenteric artery; CT, celiac trunk

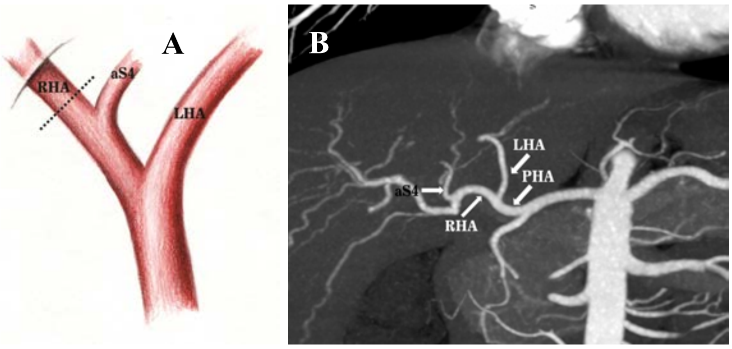

Fig. 12. Anatomical subtype 1. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; aS4, the artery to the 4th segment of the liver; the dotted line indicates the site of the RHA transection

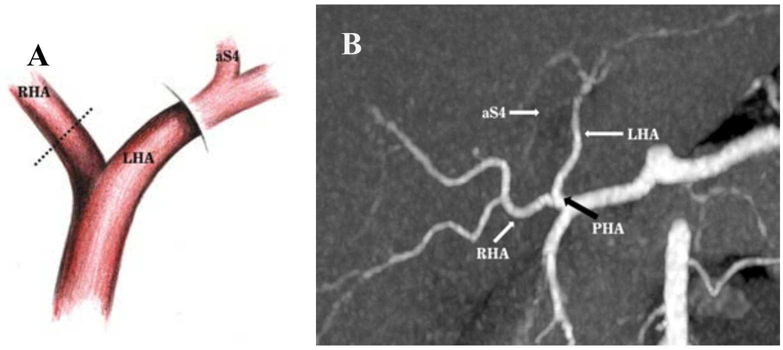

Fig. 13. Anatomical subtype 2. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; aS4, the artery to the 4th segment of the liver; the dotted line indicates the site of the RHA transection

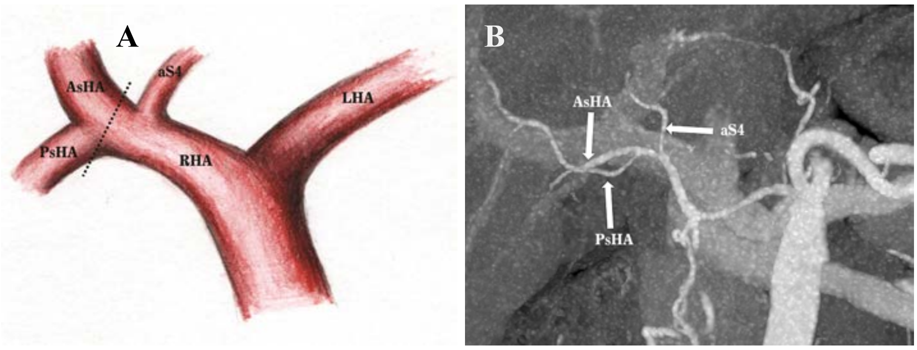

Fig. 14. Anatomical subtype 3. A, diagram; B, multilice spiral computed tomography. RHA, right hepatic artery; AsHA, anterior sectoral hepatic artery; PsHA, posterior sectoral hepatic artery; LHA, left hepatic artery; aS4, the artery to the 4th segment of the liver; the dotted line indicates the site of the RHA transection

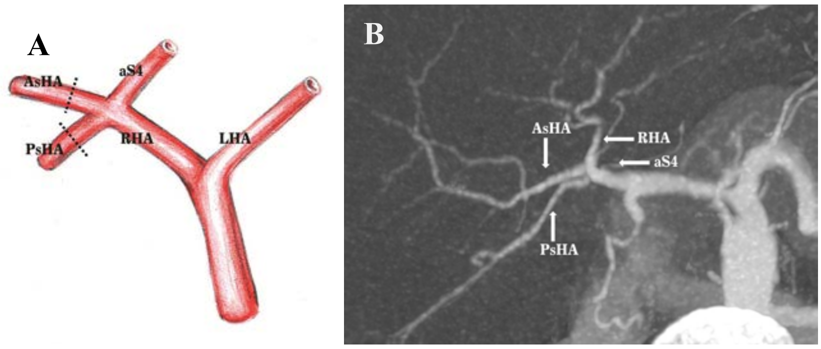

Fig. 15. Anatomical subtype 4. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; AsHA, anterior sectoral hepatic artery; PsHA, posterior sectoral hepatic artery; LHA, left hepatic artery, aS4, the artery to the 4th segment of the liver; the dotted lines indicate the sites of the AsHA and PsHA transection

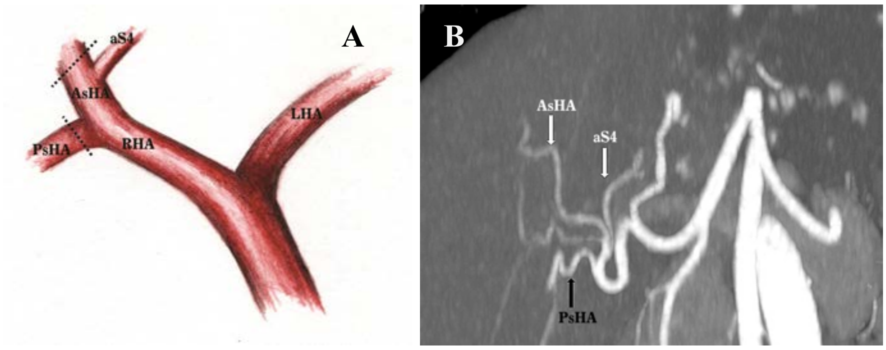

Fig. 16. Anatomical subtype 5. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; AsHA, anterior sectoral hepatic artery; PsHA, posterior sectoral hepatic artery; LHA, left hepatic artery; aS4, the artery to the 4th segment of the liver; the dotted lines indicate the sites of the AsHA and PsHA transection

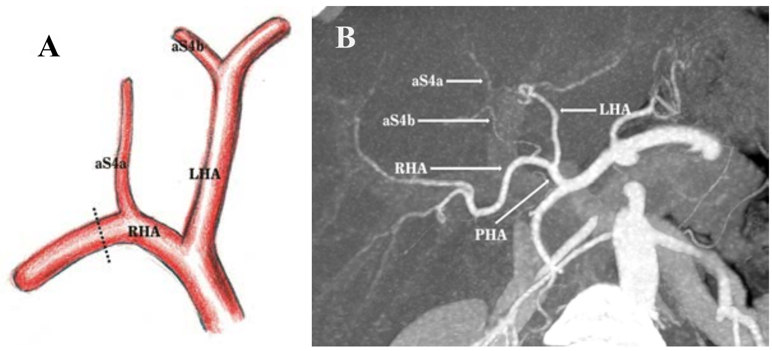

Fig. 17. Anatomical subtype 6. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; PHA, proper hepatic artery; aS4a, the artery to segment 4A of the liver; aS4b, the artery to segment 4B of the liver; the dotted line indicates the site of the RHA transection

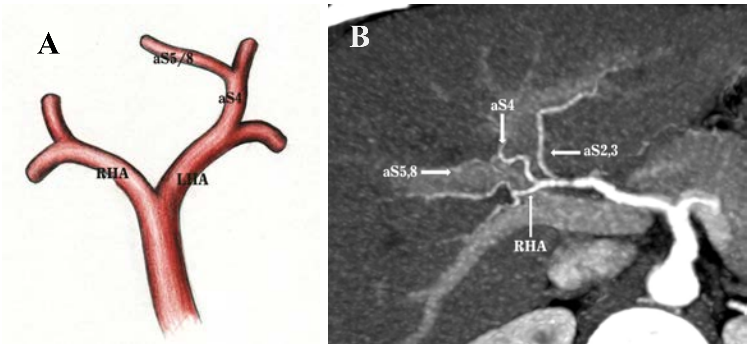

Fig. 18. Anatomical subtype 7. A, diagram; B, multislice spiral computed tomography. RHA, right hepatic artery; LHA, left hepatic artery; S4, artery to the 4^{th} segment of the liver; aS2, 3, the artery to the 2^{nd}, 3^{rd} segments of the liver, aS5, 8, the artery to the 5th, 8th segments of the liver.

The incidence of arterial postoperative complications was 3.5%, including 11 cases from the total number of operations (306) and 5.9% of the total number of patients with complications (184) (Fig. 19). An attempt at endovascular treatment of complications was made in 10 patients, which was successful in half of them. In those cases, stenting, balloon dilation, thrombectomy and local thrombolysis were performed. Four patients underwent endovascular treatment for HA stenosis, one for the HA critical kink as a result of earlier unattended kinking. Open revision of the arterial anastomosis was performed in two other patients after unsuccessful endovascular treatment (EVT), but the blood flow could not be restored. Liver retransplantation as a method of treating arterial pathology after unsuccessful EVT attempts was undertaken in 3 cases (from a related living donor in 2, from a posthumous donor in 1). In one case, retransplantation was successful. Mortality associated with the graft artery pathology was 1.9% (6 cases).

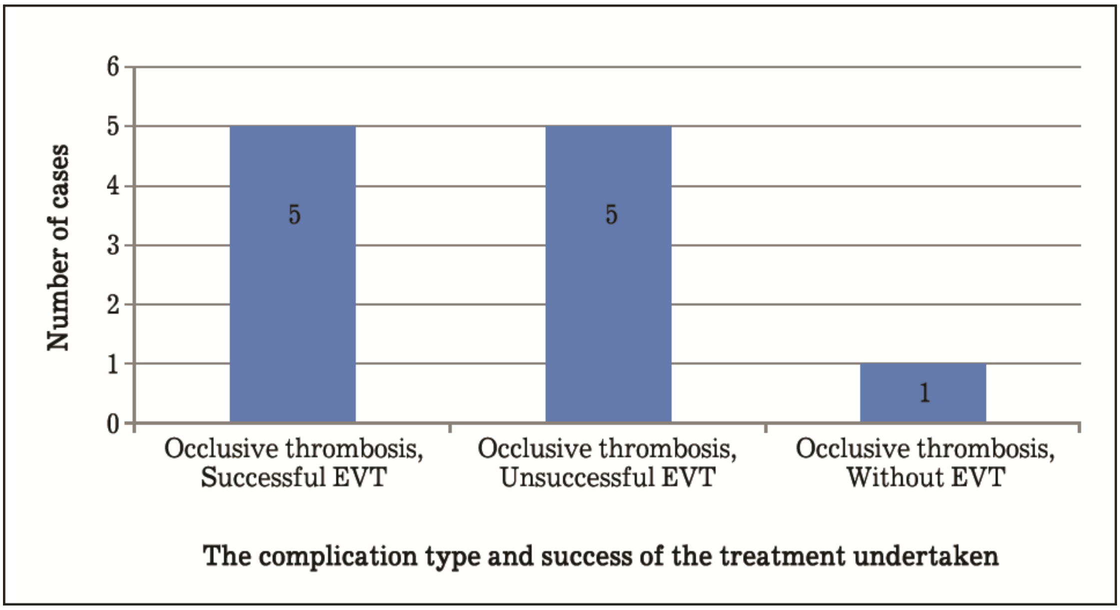

Fig. 19. Distribution by types of complications and treatment options

Discussion

Restoring arterial blood flow is a complex and critical stage of right lobe liver transplantation from a living related donor. Its success depends on many factors described above. However, given the great attention paid to the technical features of the arterial anastomosis and factors predisposing to thrombosis, the anatomical features are often neglected. In fact, unlike left lobe liver transplantation, the right lobe hepatic artery anatomy is not so variable. Cases with double or triple arterial reconstruction are relatively rare, making only 4.8%, as reported by S. M. Kim et al., whereas in transplantation of the left lobe liver or the left lateral sector, their rate reaches 26.3% [13, 14].

Multiple arteries, as a rule, have a smaller caliber, which means that the anastomosis formation may be associated with more pronounced difficulties. In this regard, some classifications are based on the number of arteries requiring reconstruction [15]. The widely cited studies by N.A. Michels, and by J.R. Hiatt, describing 10 and 6 types of the liver arterial anatomy, respectively, should certainly be considered as basic anatomical classifications; however, they are not directly related to liver transplantation as a whole, and even less so to its individual fragments [16]. In addition, there are also studies that are not directly related to RLLT, but significantly expand the concept of the liver arterial anatomy variability, for example, as in the angiographic studies by P.V. Balakhnin et al., who identified 114 variants of arterial anatomy of the liver [17].

The classification developed by G. Varotti et al. suggests the identification of 8 types of the right lobe hepatic arteries. It is based on the number of arteries, their origin, and the division of the RHA into the AsHA and PsHA [18]. A number of studies have discussed the importance of saving the artery branching off to S4 of the liver, otherwise known as the median hepatic artery. Despite the fact that there are a number of evidence that collateral blood supply often blocks the basin of the artery to liver S4, the authors emphasize the high risks of losing the 4th segment of the liver during both right and left lobe liver transplantation when ligating this vessel [19–21].

In our presented classification, the allocation of subtypes of the liver aS4 structure is based on the principle of identifying its source, which is important for choosing the site of the donor RHA transection. Thus, with subtype 3, it is possible to transect the donor RHA at the level of its division into sectoral branches and preserve the common orifice, which allows forming subsequently a single arterial anastomosis. In subtypes 4 and 5, the reconstruction of two graft arteries is necessary, since the RHA is performed at the level of its posterior and anterior sectoral branches. In subtype 6, the blood supply to aS4 originates both from the LHA and RHA systems, in which connection the transection of aS4 on the right will not lead to liver S4 ischemia, and this variant of anatomy is acceptable for donation. Subtype 7 includes situations when an entire sector or segment of the right lobe liver has a blood supply emanating from the artery to liver

S4. Donation with this type of blood supply is impossible due to the risk of losing a graft fragment. Thus, saving the artery to liver S4 is one of the key elements of donor safety, which predetermined the definition of the corresponding anatomical variants.

The proposed types of HA division are associated with certain technical nuances of liver transplantation. For example, with type B, the artery location behind the PV requires a more careful isolation of the vessel in the hepatoduodenal ligament, which must be planned at the preoperative stage, but at the same time allows obtaining a HA graft of greater than usual length. Type C is a substitutive RHA originating from any vessel system (SMA, aorta and celiac trunk, etc.) in terms of absent PHA. Type D implies the presence of an additional HA originating from any vessel system (SMA, aorta, and celiac trunk, etc.) in terms of absent PHA. In Type E donation is possible only with obtaining two HAs, which diameters are usually equivalent. Fenestration of the artery (type H) is a variant where the main trunk of the artery is divided into two full-fledged vessels and then merges distally into one [22]. We found no mentions of HA fenestration in the available literary sources. The transection of the RHA in this type should be performed at the level of the newly formed common trunk of the RHA after the merging of its branches surrounding the common bile duct (CBD), which results in the necessity of forming only one arterial anastomosis; and the blood supply to the CBD is guaranteed to be preserved. In type I, the RHA is transected just after the artery branches off to liver S4; and in type J, the donation is possible with obtaining 2 sectoral arteries of the graft. Type K implies the blood supply to the RLL from three non-duplicating each other vessels. Donation is impossible due to a complex arterial reconstruction, which creates unreasonably high risks of thrombosis

In a practical sense, the classification presented in the article can be applied as follows: first, the anatomical type of the artery is indicated, and then the associated subtype of aS4 anatomy. For example: type A (bifurcation of the PHA into the RHA and LHA) subtype 2 (the artery to S4 branches off from the LHA) is recorded as A2 hepatic artery anatomy.

Distinguishing between the types and subtypes of arterial anatomy is extremely important for a number of reasons. As stated above, preserving the artery to S4 of the liver eliminates risks unacceptable for the donor, and a full understanding of the arterial blood flow in the graft allows for adequate planning of the operation. The need to reconstruct two arteries in the donor graft creates a risk of thrombosis and the necessity for a surgeon to choose a second artery in the recipient for the reconstruction, which characteristics are not always satisfactory from the surgical point [23]. The difference in arterial diameters is also a risk factor for thrombosis, and a long stump creates the prerequisites for the development of retrograde thrombi.

Conclusion

Gaining the experience in right lobe liver transplantation from a living related donor dictates the necessity of improving the existing classifications of the right lobe hepatic arteries and implementing new classifications. There were identified 7 hepatic artery subtypes with regard to the arterial anatomy of liver segment 4 (S4) and 11 types of arterial supply to the right lobe liver, which are important for its transplantation. The arterial anatomy of the right lobe liver is a highly variable and difficult to systematize topic and requires further study in relation to the right lobe liver transplantation.

Based on the above, we can make the following conclusions:

- Requirements for the development of an optimal classification of the right lobe liver arterial supply have been formulated; based on that, we have proposed to distinguish 11 types of the right lobe arterial supply and 7 subtypes of the arterial anatomy of liver segment 4.
- The classification of hepatic arterial anatomy adapted directly to right lobe liver transplantation has been proposed.
- The classification has been successfully applied in the experience of performing 306 liver transplants from a living related donor.

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