ORIGINAL ARTICLE

Lessons Learned From Anatomic Variants of the Hepatic Artery in 1,081 Transplanted Livers

Rafael López-Andújar,[1] Angel Moya,[1] Eva Montalvá,[1] Marina Berenguer,[2] Manuel De Juan,[1] Fernando San Juan,[1] Eugenia Pareja,[1] Juan José Vila,[1] Francisco Orbis,[1] Martín Prieto,[2] and José Mir[1]
[1]*Hepatic Surgery and Liver Transplant Unit, La Fe University Hospital, Valencia, Spain;*
[2]*Hepatogastroenterology Service, La Fe University Hospital/CIBER HEPAD, Valencia, Spain*

The aim of this study is to contribute our experience to the knowledge of the anatomic variations of the hepatic arterial supply. The surgical anatomy of the extrahepatic arterial vascularization was investigated prospectively in 1,081 donor cadaveric livers, transplanted at La Fe University Hospital from January 1991 to August 2004. The vascular anatomy of the hepatic grafts was classified according to Michels description (*Am J Surg 1966;112:337-347*) plus 2 variations. Anatomical variants of the classical pattern were detected in 30% of the livers (n = 320). The most common variant was a replaced left artery arising from the left gastric artery (9.7%) followed by a replaced right hepatic artery arising from the superior mesenteric artery (7.8%). In conclusion, the information about the different hepatic arterial patterns can help in reducing the risks of iatrogenic complications, which in turn may result in better outcomes not only following surgical interventions but also in the context of radiological treatments. ***Liver Transpl 13:1401-1404, 2007.*** © **2007 AASLD.**

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Knowledge of hepatic arterial vascularization has a significant relevance for the daily practice of a wide range of practitioners including not only surgeons specialized in the hepato-biliary-pancreatic area, but also general surgeons and radiologists, mainly those who are dedicated to interventional radiologic treatments.

In the last few years, substantial improvements have been achieved in the surgical and/or radiological treatment of benign and malignant liver, pancreatic, and biliary diseases. With laparoscopic surgery the need has arisen for exact descriptions of the hepatic vascularization to avoid iatrogenic vascular lesions.

In the setting of liver transplantation, the most effective approach to reduce the dropout rate on the waiting lists is to expand the number of available livers. Several strategies including living donors and split livers have been developed for this purpose. These are extremely complex techniques in which the exact knowledge of the arterial anatomy is a required step to plan the best resection as well as to minimize the risks of morbidity.

The patterns of hepatic arterial supply are not constant. The usual anatomy of the hepatic arterial vascularization is a common hepatic artery arising from the celiac axis, accounting for 25 to 75% of the cases.[1] In the variant patterns, the hepatic lobes receive arterial flow through branches coming from the superior mesenteric artery, left gastric artery, or, rarely, from other arterial trunks.[2]

Since Michels[3] published his first report, several studies have reported not only common and rare hepatic artery variants, but also different classifications. These studies are based on angiographic data and autopsy dissections, and mainly derive from surgery and transplantation literature.[4-14]

The large sample size of transplanted livers is one of the major interests of this study. Indeed, harvested livers offer an excellent opportunity to describe, in situ, the anatomic variants of the arteries since all extrahepatic arteries need to be carefully identified during this step of the liver transplantation procedure to avoid injuries that jeopardize the viability of the graft once implanted.

The main purpose of this study is to accurately describe the anatomic hepatic artery in 1,081 donor livers. Indeed, we believe that surgical anatomy descrip-

Address reprint requests to Rafael López-Andújar, Hepatic Surgery and Liver Transplant Unit, La Fe University Hospital, Avda Campanar 21, 46009 Valencia, Spain. Telephone: 34-6-3862754; E-mail: rlopezandujar@telefonica.net

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tions have a greater value for surgeons than studies based on radiologic images or autopsy findings.

PATIENTS AND METHODS

From January 1991 to August 2004, 1,081 liver transplants were performed in the Liver Transplant Unit of La Fe University Hospital in Valencia, Spain.

All the grafts implanted for which both the procurement process and the back table surgery data were available, were included in this study. The hepatic procurement technique in the donor was carried out in all cases as described by Thomas E. Starzl in 1984,[15] following steps perfectly systematized and performed or supervised by one of the senior surgeons of the Unit. In 21 cases, the liver was explanted by the surgical team from an external center that sent it to us with the description of the in situ arterial anatomy. These cases were also included in the study since the back table procedure was always performed by a surgeon of our Unit.

Data concerning the extrahepatic arterial anatomy of the graft were prospectively recorded from every case in the donor (in situ) and ex situ surgical protocol. Arterial anatomy of the grafts were classified according to Michels[3] classification. We have also adapted the concepts of "accessory" and "replaced" artery, described by Michels.[3] If 2 hepatic arteries supply the same hepatic lobe, 1 originating in the common hepatic trunk and the other arising from a different arterial trunk, the last one is called an "accessory." On the other hand, if there is only 1 hepatic artery for the hepatic lobe, that does not arise from the common hepatic artery, it is called a "replaced" artery.

Since all the implanted livers were full grafts and given the additional risks associated with distal dissection, we avoided this practice at the back table, so there is no data on the anatomy of the middle hepatic artery.

RESULTS

Arterial variations in 1,081 organs were classified into the following 10 types (Fig. 1): 1) Type 1 (n = 761; 70%). This is the classic anatomical pattern described in anatomy books, in which the common hepatic artery arises from the celiac trunk to form the gastroduodenal and proper hepatic arteries, the latter dividing distally into right and left branches; 2) Type 2 (n = 105; 9.7%). A replaced left hepatic artery arises from the left gastric artery; 3) Type 3 (n = 84; 7.8%). A replaced right hepatic artery originates from the superior mesenteric artery; 4) Type 4 (n = 34; 3.1%). This pattern is characterized by the presence of a replaced left hepatic artery arising from the left gastric artery, and a replaced right hepatic artery originating from the superior mesenteric artery; 5) Type 5 (n = 42; 3.9%). An accessory left hepatic artery originates from the left gastric artery; 6) Type 6 (n = 7; 0.6%). An accessory right hepatic artery arises from the superior mesenteric artery; 7) Type 7 (n = 7; 0.6%). In this pattern, an accessory left hepatic artery originates from the left gastric artery, and an accessory right hepatic artery from the superior mesenteric artery; 8) Type 8 (n = 3; 0.3%). In this pattern, a replaced left hepatic artery originates from the left gastric artery, and an accessory right hepatic artery from the superior mesenteric artery or vice versa; 9) Type 9 (n = 27; 2.5%). The common hepatic artery originates from the superior mesenteric artery; and 10) Type 10 (n = 0). The common hepatic artery arises from a left gastric artery.

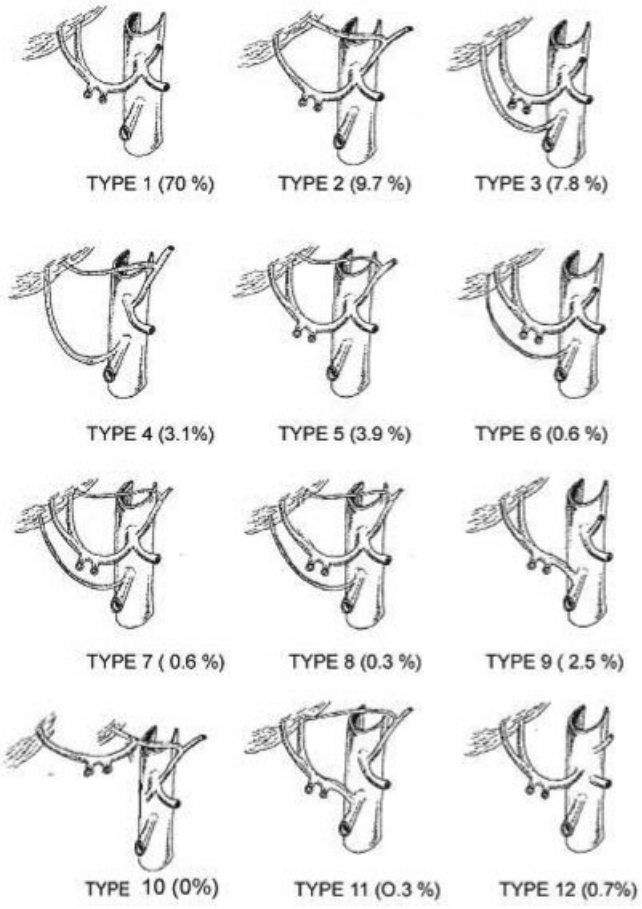

Figure 1. Hepatic arterial anatomy in 1,081 cases according to Michels' classification.[3] Percentages corresponding to each anatomical type are shown.

We also found 2 new types not included in Michels[3] classification: 1) Type 11 (n = 3; 0.3%). In this pattern, the common hepatic artery arises from the superior mesenteric artery, and an accessory left hepatic artery is a branch from left gastric artery; and 2) Type 12 (n = 8; 0.7%). The common hepatic artery originates directly from the aorta.

Overall, the percentage of patients with a double artery in the right hepatic lobe (1.5%) corresponded to the sum of the types 6, 7, and 8. On the other side, the percentage of patients with a double artery in the left hepatic lobe corresponded to types 5, 7, and 8 (5.3%).

DISCUSSION

The aim of this study is to contribute to the knowledge of the hepatic vascular anatomy with the experience

obtained in the dissection of the hepatic vascularization during liver transplantation. This concerns not only surgeons specialized in liver surgery but also general surgeons involved in open and laparoscopic operations in the upper abdomen (gastric and pancreatic surgery), and radiologists who use therapeutic modalities such as intraarterial chemoembolization of hepatic tumors; indeed, an accidental injury of any of the arterial vessels that supply the hepatic parenchyma might cause ischemia and biliary tract complications.

Our main findings can be summarized as follows: 1) The prevalence of anatomical variants was 30%, a percentage similar to that reported in other series based on surgical dissections for hepatic procurement in donors (20-29%),[5,9-11] but lower than the 39 to 46% reported in series based on autopsy cases or radiological studies[3,6-8]; 2) Most of the variants described fit into Michels[3] classification; 3) The most common anatomical variants in our series were a replaced left hepatic artery arising from the left gastric artery (9.7%) and a replaced right hepatic artery arising from the superior mesenteric artery (7.8%), in agreement with previous studies.[3-5,8,10,12]

Michels[3] reported in 1966 a classification of 10 possible anatomical variants of the extrahepatic arterial distribution that was based on a study of 200 autopsy cases. After Michels[3] initial classification, several authors described their own observations.[4-6] From a surgical point of view, we believe that Michels[3] initial classification is more complete since it establishes the differences between "an accessory" and "a replaced" artery, concepts not explained in more recent classifications. That is the main reason we choose it in the present study. Although classically it was considered that the hepatic arterial vascularization is terminal and that there are no intrahepatic communications between the different branches,[3,16] more recent data, particularly that originating from the living donor experience, has challenged this concept.[17]

We considered it important to identify all the hepatic arteries and to classify them as "accessory" or "replaced." Indeed, replaced arteries must be always preserved; in contrast, accessory arteries do not necessarily need to be reconstructed if there is adequate backflow after the anastomosis of the other branch or if arterial flow in all the segments is demonstrated by intraoperative Doppler ultrasonography.

Our study has 2 major strengths. The first is the sample size of the series, one of the largest published in the literature. The second is the material of study, an extremely meticulous dissection of the hepatic arterial vascularization by a reduced group of surgeons and with a systematized technique, taking special care in recognizing and distinguishing the difference between an accessory and replaced artery in the ex situ surgery. In fact, in our experience, a dual procurement of the liver with pancreas or small bowel was never a handicap to describing the origin of the arterial system of the explanted liver. Overall, the minimum diameter of the identified arteries was above 1 mm in adult grafts. In addition, no graft was discarded for arterial injury; in the rare cases when it occurred, it was repaired at the back table.

There are practical lessons that derive from these descriptions. In the last few years, the number of liver transplant candidates has increased substantially at a rate significantly greater than that of the donor population. This imbalance has led to the development of alternative strategies to increase the number of available organs, including living donors and split livers. Anatomical variations of the liver vasculature and bile ducts are common and their recognition and management are critical in these 2 types of liver procurement. The first living donor liver transplant using the right hepatic lobe was reported in 1994.[18] The decision to proceed with right lobectomy was forced by the intraoperative discovery of a prohibitive left lobe vascular anatomy. Replaced hepatic arteries are anomalies that are easily managed; in contrast, the presence of accessory arteries might result in reconstructions of double arteries that, because of their small diameters, are the cause of an increased rate of arterial thrombosis despite the use of refined suture techniques with magnifying glasses and microsurgery[13,14]; the concept of mandatory reconstructions when double arteries are present is, however, being revisited based on the observations about intrahepatic arterial flow in the living-donor transplantation setting.[17]

Types 2, 3, and 4, present in 21% of our cases, are favorable variants to obtain a split liver or a right hepatic lobe from a living donor, with a long and independent artery that is perfect for arterial anastomosis. Importantly, a double artery is found in 1.5% and in 5% of right or left hepatic lobes, respectively. These data can be used to decide between the right and the left hepatic lobe in the living donor. On the other side, in types 2, 4, 5, 7, 8, and 11, an accessory or replaced left hepatic artery is found in 18% of cases; information that should be taken into account in the setting of upper abdominal surgery when the gastrohepatic omentus or the left gastric artery need to be cut.

The findings of the present study highlight the fact, already observed in previous studies, that the extrahepatic arterial distribution is variable and that different anatomic variants can occur in a high percentage of cases. These arterial patterns are relevant in the planning and performance of all types of liver surgical and radiological procedures. Furthermore, knowledge of this high variability will likely help in planning and performing, with less risks of serious ischemic complications, the procurement of donor livers in all its modalities, cadaveric, living, and split livers.

REFERENCES

1. Nelson TM, Pollak R, Jonasson O, Abcarian H. Anatomic variants of the celiac superior mesenteric and inferior mesenteric arteries and clinical relevance. Clin Anat 1988; 1:75-91.
2. Braun MA, Collins MB, Wright P. An aberrant right hepatic artery from the right renal artery: anatomical vignette. Cardiovasc Intervent Radiol 1991;14:349-351.
3. Michels NA. Newer anatomy of the liver and its variant

blood supply and collateral circulation. Am J Surg 1966; 112:337-347.

4. Daly JM, Kemeny N, Oderman P, Botet J. Long-term hepatic arterial infusion chemotherapy. Arch Surg 1984;119:936-941.
5. Hiatt JR, Gabbay J,Busuttil RW. Surgical anatomy of the hepatic arteries in 1000 cases. Ann Surg 1994;220:50-52.
6. Suzuki T, Nakayasu A, Kawabe K, Takeda H, Honjo I. Surgical significance of anatomic variations of the hepatic artery. Am J Surg 1971;122:505-512.
7. Covey AM, Brody LA, Maluccio MA, Getrajdman GI, Brown KT. Variant hepatic artery anatomy revisited: digital subtraction angiography performed in 600 patients. Radiology 2002;224:542-547.
8. De Santis M, Ariosi P, Calo GF, Romagnoli R. Hepatic arterial anatomy and its variants. Radiol Med (Torino) 2000;100:145-151.
9. Merion RM, Burtch GD, Ham JM, Turcotte JG, Campbell DA. The hepatic artery in liver transplantation. Transplantation 1989;48:438-443.
10. Vicente E, Turrión VS, Nuño J, Mora NP, Pereira F. Cirugía del trasplante hepático. In: Cuervas-Mons V, ed. Trasplante Hepático. Barcelona, Spain: Editorial Mayo SA Barcelona, 1993:37-54.
11. Makisalo H, Chaib E, Krokos N, Calne R. Hepatic arterial variations and liver related diseases of 100 consecutive donors. Transpl Int 1993;6:325-329.
12. Gruttadauria S, Foglieni CS, Doria C, Luca A, Lauro A, Marino IR&rtf-scaps-start;. &rtf-scaps-end;The hepatic artery in liver transplantation and surgery: vascular anomalies in 701 cases. Clin Transplant 2001;15:359-363.
13. Marcos A, Ham JM, Fisher RA, Olzinski AT, Posner MP. Surgical management of anatomical variation of the right lobe in living donor liver transplantation. Ann Surg 2000; 231:824-831.
14. Nakamura T, Tanaka K, Kiuchi T, Kasahara M, Oike F, Ueda M, et al. Anatomical variations and surgical strategies in right lobe living donor liver transplantation: lessons from 120 cases. Transplantation 2002;73:1896-1903.
15. Starzl TE, Hakala TR, Shaw BW Jr, Hardesty RL, Rosenthal TJ, Griffith BP, et al. A flexible procedure for multiple cadaveric organ procurement. Surg Gynecol Obstet 1984;158:223-230.
16. Miyaki T, Sakagami S, Ito H. Intrahepatic territory of the human. Acta Anat (Basel) 1989;136:34-37.
17. Ikegami T, Kawasaki S, Matsunami H, Hashikura Y, Nakazawa Y, Miyagawa S, et al. Should all hepatic arterial branches reconstructed in living-related liver transplantation?. Surgery 1996;119:431-436.
18. Yamaoka Y, Washida M, Honda K, Tanaka K, Mori K, Shimahara Y, et al. Liver transplantation using a right lobe graft from a living related donor. Transplantation 1994;57:1127–1130.