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## ► To cite this version:

Astrid Herrero, Regis Souche, Emmanuel Joly, Gildas Boisset, Hussein Habibeh, et al.. Early Hepatic Artery Thrombosis After Liver Transplantation: What is the Impact of the Arterial Reconstruction Type?. World Journal of Surgery, 2017, 41 (8), pp.2101 - 2110. 10.1007/s00268-017-3989-4 . hal-01774050

**HAL Id: hal-01774050**

**<https://hal.science/hal-01774050>**

Submitted on 16 Dec 2019

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# Early Hepatic Artery Thrombosis After Liver Transplantation: What is the Impact of the Arterial Reconstruction Type?

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**Abstract**

*Objective* Hepatic artery thrombosis (HAT) is the most severe vascular complication occurring after liver transplantation, with an incidence ranging from 2 to 9% in adults. Although the ideal arterial reconstruction is often described as a short and non-redundant anastomosis fashioned between the recipient and donor hepatic arteries, there is no strong evidence about this ideal reconstruction in the literature. The aim of this study was to assess the impact of the type of arterial reconstruction on early HAT after primary liver transplantation.

*Methods* We retrospectively reviewed a contemporary MELD era cohort of 282 patients who underwent deceased donor primary liver transplantation from 2007 to 2012. Graft artery was classified as “short” when the section was located at the proper/common hepatic artery or “long” when the celiac trunk was used for anastomosis. Recipient arterial sites for arterial anastomosis were classified in three sites: (1) “distal” (proper hepatic artery or common hepatic artery/gastro-duodenal bifurcation), (2) “intermediate” (common hepatic artery) and (3) “proximal” (celiac trunk–splenic artery–aorta). We used univariate and multivariate analyses to assess the impact of different types of arterial reconstruction on early HAT.

*Results* Of 282 primary liver transplantations, 17 patients (6%) developed early HAT. Patients with and without early HAT had comparable demographic and operative data. The main anastomotic combination was short graft artery on the recipient-common hepatic artery ( $n = 111$ , 39%). A long graft artery was used in 91 patients (32%) and was associated with hepatic artery variations (56%;  $n = 51$ ;  $p = 0.001$ ). Arterial reconstructions using a long graft artery ( $p = 0.003$ ), a recipient proximal site as celiac trunk–splenic artery–aorta ( $p = 0.02$ ) and the combination of a long graft artery on the recipient distal hepatic artery ( $p = 0.02$ ) were significantly associated with early HAT. The early HAT rate in patients with a long graft artery was not significantly different between patients with or without donor arterial variation (respectively, 12% ( $n = 6/51$ ) vs. 12% ( $n = 5/40$ );  $p = 1$ ). In multivariate analysis, the use of a long graft artery, whatever the recipient anastomosis site, was an independent risk factor of early HAT (OR 3.2; 95% CI 1.2–9;  $p = 0.02$ ).

*Conclusion* The type of arterial reconstruction used for arterial anastomosis during primary liver transplantation has an impact on the occurrence of early HAT. The use of a long graft artery is an independent risk factor of early HAT. Thereby, we recommend the use of a short graft artery with a direct path when feasible to reduce the occurrence of early HAT after primary liver transplantation.

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## Abbreviations

A	Aorta
AA	Arterial anastomosis
CHA	Common hepatic artery
CT	Celiac trunk
CT scan	Computed tomography scan
GDA	Gastroduodenal artery
GS	Graft survival
HA	Hepatic artery
HAT	Hepatic artery thrombosis
ICU	Intensive care unit
LT	Liver transplantation
MELD	Model for end-stage liver disease
OS	Overall survival
PHA	Proper hepatic artery
RRHA	Replaced right hepatic artery
SA	Splenic artery
SMA	Superior mesenteric artery
TACE	Transarterial chemoembolization
POD	Postoperative day

## Introduction

Liver transplantation (LT) is a life-saving treatment for patients with end-stage liver disease, acute liver failure or hepatocellular carcinoma [1–4]. Vascular complications after LT increase postoperative morbidity and contribute to subsequent primary graft dysfunction, ischemic biliary complications and long-term graft loss [5–7]. Hepatic artery thrombosis (HAT) is the most severe vascular complication with an incidence ranging from 2 to 9% in adults [6–11]. Anatomical or technical causes of early HAT occurring within 1 month after LT remain unclearly identified. Although Dokmak et al. [12] described the ideal arterial reconstruction as a short and non-redundant anastomosis fashioned between the recipient and donor hepatic arteries, there is no strong evidence about this ideal reconstruction in the literature. In deceased donor LT, arterial anastomosis (AA) depends on a combination of donor and recipient artery diameters, vessel quality, donor/recipient anatomical variations and specific conditions related to the indication

for LT. We purposed to describe and analyze these combinations using a simple classification for donor and recipient sites used for arterial anastomosis. The aim of this study was to clarify the impact of the type of arterial reconstruction on early HAT occurrence after primary LT involving whole organ graft in a contemporary model for end-stage liver disease (MELD) cohort.

## Patients and methods

### Study definition

We analyzed a prospectively maintained database of 338 patients undergoing liver transplantation at the University of Montpellier teaching hospital (France) from January 1, 2007, to October 31, 2012. Monitoring was carried out until December 2014 with a median follow-up of 39 months (range: 32–630 months). All liver grafts were from deceased donors. Patient with primary LT involving whole organ graft was included in this study. Patients with (1) LT before the study period and retransplantation during the study period, (2) requiring arterial conduit (donor iliac artery, vein interposition, prosthetic grafts), (3) primary graft non-function or (4) split liver transplantation were excluded. Results of arterial reconstruction after retransplantation for included patients were not analyzed. The main criterion was early HAT occurring within 1 month post-LT, defined as a lack of arterial flow determined by Doppler ultrasound and confirmed by a computed tomography scan (CT scan). Preoperative evaluation, surgical data, postoperative complications, 90-day mortality and hospital stay were recorded. Arterial reconstructions during retransplantation were not analyzed, and patients with missing data >5% were excluded.

### Preoperative evaluation, surgery and follow-up

After a preoperative visit including a CT scan, all cases were discussed in the multidisciplinary transplantation meeting to assess the arterial anatomy of the recipient and discuss technical options. As recommended, the patency and size of the hepatic artery (HA) as well as the identification of any variation that could result in reduced flow of the HA were systematically analyzed with a radiologist [13, 14].

Donor liver recovery was done by four experienced fellows with the no arterial touch technique and dissection of the arteries on back-table [15, 16]. Preservation of the donor livers was done using the IGL1® (Waters medical systems, USA), Celsior® (Genzyme Polyclon S.A.S., France) or Viaspan® (Bristol-Myers Squibb, USA) solutions in 76, 19 and 5%, respectively.

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In case of donor arterial variations, senior surgeons performed back-table reconstruction if required. Donor's right hepatic artery variation (Type III and IV) was reconstructed using Gordon technique, anastomosis with either donor gastroduodenal artery or splenic artery [17, 18]. These three types of reconstruction were defined as a complex arterial reconstruction. A replaced left hepatic artery did not justify reconstruction and was managed with an anastomosis between a Carrel patch of donor celiac trunk and recipient artery [18].

Most liver transplantations were performed using piggy-back surgical technique under this sequence: (1) a caval anastomosis (latero-lateral, three-vein technique [19] or end-to-end), (2) an end-to-end portal anastomosis, (3) an arterial anastomosis and (4) a duct-to-duct biliary anastomosis. No porto-caval shunt was used. A sequential revascularization was done, and the graft was first perfused via the portal vein and then via the hepatic artery. In our protocol, recipients received anti-thrombin III to maintain the anti-thrombin rate above 70% in the first postoperative days. In addition to systematic intermittent compression stockings, in the absence of any hemorrhagic complications and/or low platelet count <50 000 ml, all patients received heparin to maintain an activated partial thromboplastin time at 1.5–2.0 fold the baseline value and later substituted with prophylactic low molecular weight heparin. Acetylsalicylic acid was reserved for elderly donors (age > 70 year old), patients with atheromatosis, small arteries (diameter < 5 mm) and/or complex arterial reconstruction [20].

Postoperative arterial patency was examined by Doppler ultrasound during the first week at postoperative days 1, 3 and 5 routinely. Subsequent examinations were carried out as indicated clinically.

## The arterial anastomosis

The arterial reconstruction was planned before the transplantation to reduce prolonged warm ischemia (number, size and quality of the donor and recipient arteries). The flow of the recipient HA was evaluated by observation and pulse palpation after the total hepatectomy. In case of inadequate HA flow (small hepatic artery, intraoperative intimal dissection, mass ligation of hepatic pedicles in patients with portal cavernoma), dissection of the common hepatic artery (CHA) and then of the recipient celiac trunk (CT) was performed to determine the future site of arterial anastomosis (AA). On a case-by-case basis, an adapted and oriented arterial anastomosis with intima-to-intima opposition was fashioned under a surgical loop with a running or separated 6-0 or 7-0 polypropylene suture. When arterial reconstruction was redundant with a long conduit, omental flap or interposition of hemostatic sealants was used to prevent arterial kinking.

## Definition of graft artery length and recipient arterial sites

Graft artery length was prospectively defined as “short” when the section was located at the common hepatic artery or “long” when the celiac trunk was used for anastomosis (Carrel patch [17]). In cases of donor right hepatic artery, the Gordon technique or a reconstruction using donor splenic artery was considered as a long graft artery. On the other hand, a reconstruction using donor gastroduodenal artery resulted in a short graft artery.

Recipient arterial sites for AA were classified in three sites: (1) proper hepatic artery or common hepatic artery/gastro-duodenal bifurcation (PHA or CHA/GDA bifurcation = *distal site*), (2) common hepatic artery (CHA = *intermediate site*) and (3) celiac trunk–splenic artery–aorta (CT-SA-A = *proximal site*).

All the arterial anastomoses were therefore classified according to 6 types of arterial reconstruction.

## Statistical analysis

Variables were compared between patients with and without early HAT with Chi-square test, Fisher's exact test or Student's *t* test, as appropriate. All variables with  $p < 0.10$  in univariate analysis were studied in a multiple logistic regression model. A  $p$  value less than 0.05 was considered as statistically significant. Patient overall survival (OS) and graft survival (GS) were calculated with the Kaplan–Meier method. Survival was compared between groups using the log-rank test. Statistical analyses were performed using SPSS Statistics, version 20.0, for Macintosh (IBM Corp, Armonk, NY) and GraphPad Prism, version 5.00, for Windows (GraphPad Software, San Diego, CA).

## Results

### Demographic and operative data

During the study period, 282 patients with primary liver transplantation involving whole organ graft were included. The recipients were 212 men and 70 women, with a mean age of 53 years (range 17–76). Patient characteristics and comorbidities are detailed in Table 1. Prominent indications were (1) alcoholic liver disease in 56.4%, (2) viral hepatitis in 27% and (3) non-alcoholic liver steatohepatitis in 8% of patients. Hepatocellular carcinoma was present in 105 patients (37.2%), and 52 of them (18%) had been treated by transarterial chemoembolization before LT (1–3 treatments per patients). Patients were Child–Pugh score A, B or C in 19, 22 and 54%, respectively. The median MELD



**Table 1** Pretransplant recipient characteristics

Variables	Patients	HAT <i>n</i> (%)	No HAT <i>n</i> (%)	<i>P</i> value
Number of LTs, <i>n</i>	282	17	265	
Demographics				
Age (year) median $\pm$ SD	53 $\pm$ 10	48 $\pm$ 10	54 $\pm$ 10.5	0.06
Sex, male, <i>n</i> (%)	212 (75)	14 (82)	198 (74)	0.48
Comorbidities				
BMI, kg/m <sup>2</sup> , median $\pm$ SD	25 $\pm$ 4	24 $\pm$ 3	25 $\pm$ 4	0.10
Hypertension, <i>n</i> (%)	68 (24)	2 (11)	66 (25)	0.22
Diabetes, <i>n</i> (%)	48 (17)	1 (6)	47 (18)	0.20
Chronic renal failure, <i>n</i> (%)	16 (6)	3 (18)	13 (5)	0.06
Coronary artery disease, <i>n</i> (%)	34 (12)	0 (0)	34 (13)	0.23
Earlier susmesocolic operation, <i>n</i> (%)	53 (19)	3 (18)	50 (19)	0.93
Pretransplant acuity				
MELD, median $\pm$ SD	20 $\pm$ 10	25 $\pm$ 11	20 $\pm$ 10	0.12
Child A, <i>n</i> (%)	54 (19)	4 (24)	50 (19)	0.74
Child B, <i>n</i> (%)	62 (22)	3 (18)	59 (22)	1
Child C, <i>n</i> (%)	153 (54)	9 (53)	144 (54)	0.91
UNOS status				
No hospitalized	187 (66)	8 (47)	179 (66)	0.08
Conventional hospitalization	43 (15)	5 (30)	38 (14)	0.15
ICU hospitalization	52 (18)	4 (24)	48 (18)	0.52
Causes of liver disease, <i>n</i> (%)				
Viral hepatitis	75 (27)	5 (30)	70 (26)	0.78
ALD	159 (56)	11 (65)	148 (56)	0.61
NASH	22 (8)	2 (11)	20 (8)	0.95
Acute liver failure	9 (3)	0 (0)	9 (3)	1
PBC/PSC	21 (7)	3 (18)	18 (7)	0.13
Other	29 (10)	0 (0)	29 (11)	0.23
Hepatocellular carcinoma, <i>n</i> , (%)	105 (37)	8 (47)	97 (37)	0.98
Pretransplant TACE	52 (18)	3 (18)	49 (18)	1

*HAT* hepatic artery thrombosis, *LT* liver transplantation, *BMI* body mass index, *MELD* model for end-stage liver disease, *ICU* intensive care unit, *ALD* alcoholic liver disease, *NASH* non-alcoholic steatohepatitis, *PBC* primary biliary cirrhosis, *PSC* primary sclerosing cholangitis, *TACE* transarterial chemoembolization

score was 20 (range: 6–46). Before LT, according to the UNOS Criteria, patients were discharged, hospitalized or in ICU in 66, 15 and 18% of cases, respectively. Donor characteristics and operative data are detailed in Table 2.

### Arterial anatomy and types of reconstruction

Graft arterial anatomy was classic (Type I) in 206 patients (73%). We found donor arterial variations in 76 patients (27%): a replaced left hepatic artery (RLHA; Type II) in 25 patients (9%), a replaced right hepatic artery (RRHA; Type III) in 35 patients (13%), replaced left and right arteries (Type IV) in 13 patients (4%) and a CHA from SMA (Type V) in three patients (1%).

The length of graft artery was mainly short (68%, *n* = 191).

In recipients, used sites were intermediate (CHA) in 61% (*n* = 172), distal (PHA or CHA/GDA bifurcation) in 35% (*n* = 98) and proximal (CT–SA–A) in 4% with inadequate HA flow (*n* = 12) of patients.

Most common reconstructions were short graft artery on the recipient CHA (*n* = 111, 39%), short graft artery on recipient “PHA or CHA/GDA bifurcation” (*n* = 74, 26%), long graft artery on CHA (*n* = 61, 22%) and long graft artery on “PHA or CHA/GDA bifurcation” (*n* = 24, 9%).

A long graft artery was used in 91 patients (32%). These long graft arteries resulted from arterial variations in 51 cases (56%) requiring (1) a complex reconstruction in 26

**Table 2** Donor and operative data

Variables	Patients ( <i>n</i> = 282) <i>n</i> (%)	HAT ( <i>n</i> = 17) <i>n</i> (%)	No HAT ( <i>n</i> = 265) <i>n</i> (%)	<i>p</i> value
Donor characteristics				
Age (year) median ± SD	52 ± 15	49 ± 13	52 ± 15	0.60
<70 year old	234 (83)	14 (82)	220 (83)	–
>70 year old	48 (17)	3 (18)	45 (17)	0.74
Sex, male, <i>n</i> (%)	172 (61)	10 (59)	162 (61)	0.84
BMI (kg/m <sup>2</sup> ) median ± SD	25 ± 4	25 ± 4	25 ± 6	0.49
Operative characteristics				
CIT (min) median ± SD	452 ± 116	480 ± 112	450 ± 117	0.31
WIT (min) median ± SD	65 ± 28	73 ± 22	67 ± 27	0.48
Transfusion (U) median ± SD	7 ± 4	8 ± 4	7 ± 4	0.68
Fresh frozen plasma ± SD	8 ± 6	9 ± 6	8 ± 6	0.57
Biliary reconstructions				
Choledochocholedochostomy	257 (91)	15 (88)	242 (91)	–
Roux-en-Y choledochojejunostomy	25 (8)	2 (12)	23 (9)	0.64
T tube	70 (24)	6 (35)	64 (24)	0.30

*HAT* hepatic artery thrombosis, *BMI* body mass index, *CIT* cold ischemia time, *WIT* warm ischemia time

patients by Gordon technique (*n* = 13) or an anastomosis between a replaced right hepatic artery and donor SA (*n* = 13), (2) a Carrel patch of CT (*n* = 25).

A Carrel patch of CT was performed in 40 cases (44%) with classic donor arterial anatomy according to the surgeon habit or recognition of small donor arteries (<5 mm).

Arterial anatomy and types of reconstruction are detailed in Table 3.

Acetylsalicylic acid therapy was introduced intraoperatively in 114 patients (40%) conforming to the surgical team recommendation due to complex arterial reconstruction (*n* = 37, 32%), atheromatosis (*n* = 33, 29%), elderly donors (*n* = 24, 21%) and/or patients with small arteries (*n* = 20, 18%).

**Incidence and presentation of HAT**

Early HAT was diagnosed in 17 (6%) of the 282 patients with LT with a median delay of 3 days after LT (range: 1–25). Late HAT occurred in 2% of patients (*n* = 6) with a median delay of 191 days (range: 65–223). Presentation of early HAT included elevated transaminases in 73% of cases, biliary complications in 18%, fever and sepsis in 7% and graft dysfunction or failure in 5%.

**Management of early HAT, outcomes and survival analysis**

Of the 17 patients with early HAT, 11 patients underwent surgical treatment with thrombectomy and re-anastomosis,

4 patients received medical treatment (acetylsalicylic therapy (*n* = 3), endovascular treatment with a stent (*n* = 1)) and two patients underwent retransplantation (at POD 7 and 21). The ninety-day mortality of patients with early HAT was 23% (*n* = 4, one patient with surgical treatment, one patient with reLT and two patients with medical treatment). Early HAT increased significantly recipient mortality (HR = 3.88; 95% CI 3.38–46.54; *p* = 0.0002) and graft loss (HR = 5.85; 95% CI 2.37–90; *p* = 0.01) as shown in Figs. 1, 2, respectively.

**Analysis of risk factors of early HAT**

Demographic and operative data of patients with and without early HAT are compared in Tables 1, 2, respectively. No difference was found concerning donor/recipient age, donor/recipient gender, comorbidities, UNOS criteria, causes of liver disease, previous transarterial chemoembolization and surgeon.

Types of arterial reconstruction and their results are described in Fig. 3 and Table 3. Concerning the length of the graft artery, the rate of early HAT was greater with a long graft artery than with a short graft artery (12% vs. 3%; *p* = 0.003).

Although donor arterial variation (56% (*n* = 51/91) vs. 14% (25/191), *p* = 0.001) and complex reconstruction (29% (*n* = 26/91) vs. 12% (22/191), *p* = 0.006) were significantly associated with a long graft artery compared to short graft artery, these two variables were not significantly associated with early HAT (respectively, *p* = 0.08

**Table 3** Arterial anatomy, types of reconstruction and HAT prevention

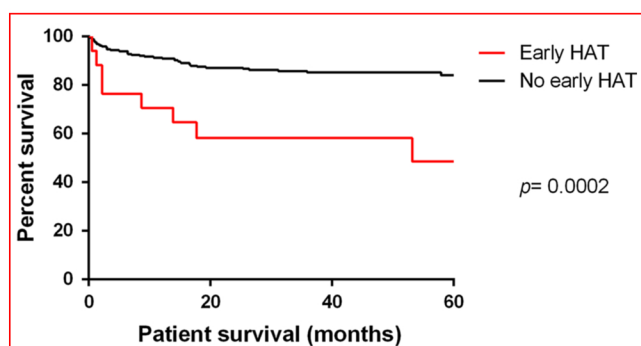
Variables	Patients ( <i>n</i> = 282) <i>n</i> (%)	HAT ( <i>n</i> = 17) <i>n</i> (%)	No HAT ( <i>n</i> = 265) <i>n</i> (%)	<i>p</i> value
Donor arterial anatomy				
Classic (Type I)	206 (73)	10 (59)	196 (74)	–
Variations	76 (27)	7 (41)	69 (26)	0.08
Replaced left hepatic artery (Type II)	25 (9)	3 (18)	22 (8)	0.67
Replaced right hepatic artery (Type III)	35 (13)	1 (6)	34 (13)	0.11
Replaced right and left arteries (Type IV)	13 (4)	2 (12)	11 (4)	0.34
CHA from SMA (Type V)	3 (1)	1 (6)	2 (1)	0.25
Donor artery length				
Short	191 (68)	6 (35)	185 (70)	–
Long	91 (32)	11 (65)	80 (30)	0.003
Recipient sites				
PHA or CHA-GDA bifurcation	98 (35)	5 (30)	93 (35)	0.79
CHA	172 (61)	9 (53)	163 (62)	0.48
CT/SA/Aorta	12 (4)	3 (18)	9 (3)	0.02
Anastomotic combinations				
Short				
PHA or CHA-GDA bifurcation	74 (26)	1 (6)	73 (28)	–
CHA	111 (39)	4 (24)	107 (40)	0.64
CT/SA/Aorta	6 (2)	1 (6)	5 (2)	0.14
Long				
PHA or CHA-GDA bifurcation	24 (9)	4 (23)	20 (8)	0.02
CHA	61 (22)	5 (30)	56 (21)	0.26
CT/SA/Aorta	6 (2)	2 (12)	4 (2)	0.57
Donor small arteries (<5 mm)				
No	262 (92)	14 (82)	248 (94)	–
Yes	20 (8)	3 (18)	17 (6)	0.08
Complex arterial reconstruction*				
No	234 (87)	14 (82)	220 (87)	–
Yes	48 (13)	3 (18)	45 (13)	0.98
Gordon	13 (5)	2 (12)	11 (4)	0.20
RRHA on donor GDA	22 (8)	1 (6)	21 (8)	0.99
RRHA on donor SA	13 (5)	0 (0)	13 (5)	0.99
Arterial kinking prevention				
No	206 (73)	15 (89)	191 (72)	–
Yes	76 (27)	2 (18)	74 (28)	0.14
Omental flap	65 (23)	1 (6)	64 (24)	0.12
Hemostatic sealant	11 (4)	1 (6)	10 (4)	0.83
Postoperative acetylsalicylic acid therapy				
No	168 (60)	8 (47)	160 (60)	–
Yes	114 (40)	9 (53)	105 (40)	0.31

*HAT* hepatic artery thrombosis, *CHA* common hepatic artery, *SMA* superior mesenteric artery, *PHA* proper hepatic artery, *GDA* gastroduodenal artery, *CT* celiac trunk, *SA* splenic artery, *RRHA* replaced right hepatic artery

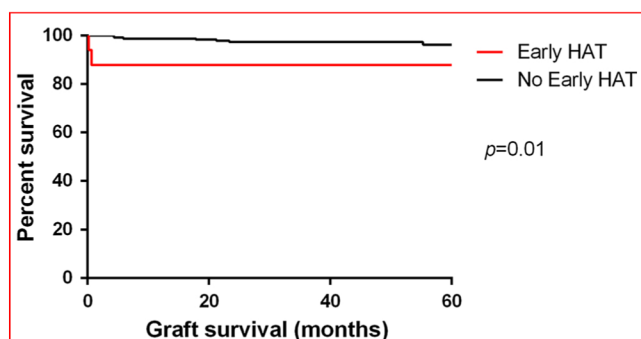
\* More than 1 arterial anastomosis (Gordon: end-to-end anastomosis between SMA and CT during back-table)

and  $p = 0.98$ ). The early HAT rate in patients with a long graft artery was not significantly different between LT with or without donor arterial variation (respectively, 12%

( $n = 6/51$ ) vs. 12% ( $n = 5/40$ );  $p = 1$ ) and with or without complex reconstruction (respectively, 8% ( $n = 2/26$ ) vs. 14% ( $n = 9/65$ );  $p = 0.50$ ). No association was found



**Fig. 1** Patient survival according to early HAT



**Fig. 2** Graft survival according to early HAT

between the type of donor arterial variation and the occurrence of early HAT.

Concerning recipient arterial sites, the need to use a proximal arterial site (aorta–celiac trunk–splenic artery) was associated with early HAT ( $p = 0.02$ ).

Arterial reconstruction using a long graft artery on distal recipient arterial site (PHA or CHA/GDA bifurcation) was associated with an increased rate of early HAT compared with reconstruction on other sites ( $p = 0.02$ ). No difference was found between recipient sites of implantation when using a short graft artery. In addition, no significant benefit was found in the group of patients who received prophylactic acetylsalicylic acid therapy ( $p = 0.31$ ).

Six variables with  $p < 0.100$  data on univariate analysis were integrated in the multivariate model and are detailed in Table 4: median recipient age, recipient chronic renal failure, donor arterial variation, donor small artery ( $<5$  mm), long graft artery and proximal recipient arterial site.

Multivariable logistic regression analysis including the potential confounding factor “donor arterial variation” identified the use of a long graft artery as an independent risk factor associated with early HAT after LT (OR 3.2; 95% CI 1.2–9;  $p = 0.02$ ).

In the group of patients with early HAT, the use of a long graft artery did not decrease the use of

retransplantation ( $p = 0.11$ ) and did not improve patient survival ( $p = 0.09$ ) or graft survival ( $p = 0.22$ ).

## Discussion

### Statement of the principal findings

In a cohort of consecutive patients who underwent deceased donor primary LT in the MELD era, we observed an early HAT rate of 6%. This study analyzing the impact of the type of arterial reconstruction on HAT showed that the use of a long graft artery was an independent risk factor of early HAT. In addition, a “long conduit” resulting from the combination of a long graft artery anastomosed on a distal recipient arterial site, as the PHA-CHA/GDA bifurcation, was significantly associated with early HAT. Although the type of arterial reconstruction has already been studied in several series according to the implantation site and is a known HAT risk factor, the length of the donor artery has never been analyzed. We showed in this study that there was no difference between recipient sites of implantation when using a short graft artery in terms of early HAT rate.

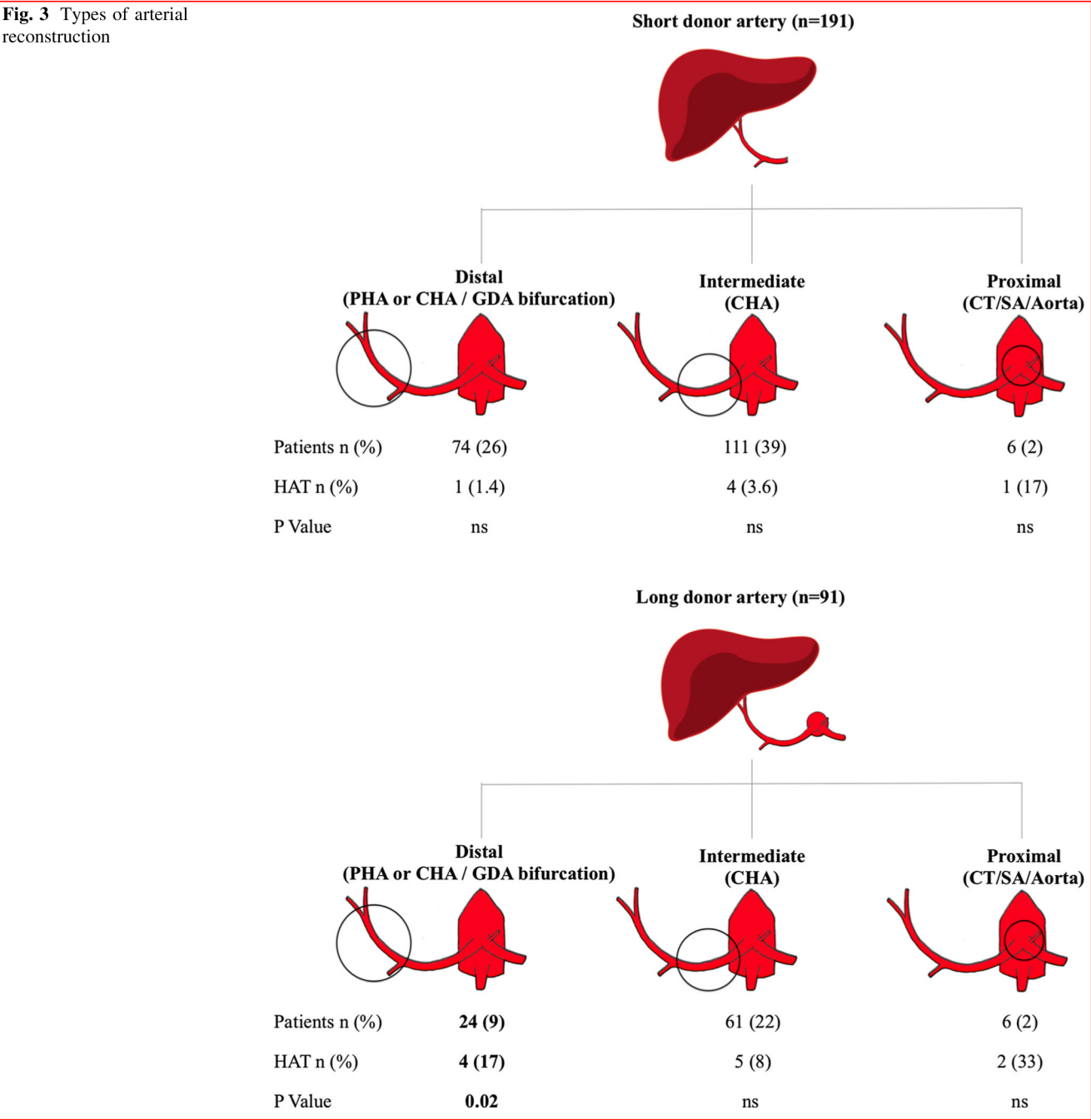
### Interpretation with reference to the published literature

The early HAT rate of 6% and the ratio between early and late HAT are in line with previous reports analyzing HAT occurrence after deceased donor LT [7, 8]. Patients with and without early HAT were comparable on main demographic and operative data and allowed us to focus our analysis on anatomical considerations for arterial reconstruction. Complex arterial reconstruction [21] and pretransplant TACE [7] have been identified as risk factors in previous reports but were not associated with an increased risk of early HAT in the present study. Several reports have shown histological injuries in patients who underwent pretransplant TACE, but these lesions occurred downstream the proper hepatic artery [22], did not seem to increase HAT occurrence and were associated with hepatic artery stenosis [23], as in our report (data not shown).

Two technical approaches are described for arterial reconstruction in clinical practice [24, 25]: either keeping a long graft artery offering a better lumen diameter [7, 26]; or splitting the graft artery to obtain a more anatomical, non-redundant conduit [12, 18]. The first conservative approach should facilitate the management of potential post-LT arterial complications, whereas the latter results in a smaller lumen diameter and potential difficulties in case of reoperation for arterial complications. Our current findings strongly suggest that arterial anastomosis most



**Fig. 3** Types of arterial reconstruction



closely restoring normal anatomy is of paramount importance to prevent early HAT.

Although using a long graft artery was associated with arterial anatomical variation as expected (56%), the negative effect of this type of reconstruction persisted in the subgroup of patients who underwent an anastomosis using a long graft artery without context of replaced arteries (44%). Merion et al. [27] showed in 1989 that the use of a Carrel patch reduced the occurrence of HAT; this positive effect disappeared when the anastomosis was done on proper hepatic artery. In line with the present study, the risk

of HAT was significantly higher with a long conduit resulting from a long graft artery anastomosed on the recipient's proper hepatic artery than on the recipient's common hepatic artery [27]. Our results highlight the need for a compromise between arterial diameter and arterial length according to Poiseuille's law which define the volume flowrate ( $\text{Volume flowrate} = (\pi (\text{Pressure difference}) (\text{radius})^4) / (8 (\text{Viscosity}) (\text{Length}))$ ).

Although many methods have been described to prevent HA kinking, such as omental flap or interposition of hemostatic sealants [25, 28], a long graft artery seems to be

**Table 4** Results of multivariate logistic regression analysis for risk factors of early HAT (Hosmer–Lemeshow goodness of fit *p* value = 0.48)

Variables	OR	95% CI	<i>p</i> value
Recipient age (year)	1.25	1.16–4.12	0.18
Recipient chronic renal failure*	6.48	1.83–22.48	0.10
Donor arterial variation	2.57	0.95–6.94	0.08
Long graft artery	3.24	1.21–8.82	0.02
Recipient site: CT/SA/Aorta	6.09	1.48–25.04	0.27

CT celiac trunk, SA splenic artery

\* Creatinine clearance (Cockcroft–Gault) < 60 ml/min/1.73m<sup>2</sup>

more exposed to kinking or at least to leukocytes/platelets aggregation, which contributes to reduced arterial flow and thrombus formation. To our knowledge, there is no evidence that using a long graft artery could improve the management of potential post-LT arterial complications. In case of early HAT, no difference was found in patient/graft survivals between patients with long or short graft arteries, suggesting that there is no obvious benefit of using a long graft artery to improve surgical management of potential HAT.

**Strength and weakness of the study**

The main strength of this study is the prospective review of arterial reconstructions and the analysis of its impact on early HAT in a large single-center experience in LT. The present study has some limitations. First, this study had a sample size that probably enabled us to show an influence of demographic and other operative factors on HAT occurrence (Type II error ( $\beta$ )). Second, our data indicated that grafts from the recipient’s aorta–celiac trunk–splenic artery were significantly associated with HAT, but the small size of this subgroup and potential confounding factors have to be considered (atheromatosis, preoperative recipient arterial dissection justifying this reconstruction in a primary LT). Third, the limited number of patients who developed early HAT does not allow us to conclude on the type of arterial reconstruction that improves surgical management of HAT. These limits highlight the need for further larger multi-center prospective studies.

**Conclusion**

This study reports the scope of arterial reconstruction types in a contemporary MELD era cohort and showed that early HAT is still a serious complication after primary LT, affecting graft and patient survival rates. Use of a long graft artery was an independent factor associated with early

HAT and can be a potentially modifiable technical factor. Thereby, we recommend the use of a short graft artery with a direct path when feasible to reduce the occurrence of early HAT after primary liver transplantation.

**Authors’ contribution** AH, RS, EJ and FN designed the paper, reviewed the literature, collected data, wrote the paper and contributed important ideas. GB, HH, HB, FP, JUB, SJ, BG, GPP designed the paper, collected data and contributed important ideas.

**Compliance with ethical standards**

**Conflicts of interest** The authors declare no conflicts of interest.

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