Hepatic Arterial Supply in 1297 CT-Angiographies

Die arterielle Leberversorgung in 1297 CT-Angiografien

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Key words
- hepatic arteries
- CT-angiography
- anatomy

received 22.7.2014
accepted 14.11.2014

Bibliography
DOI http://dx.doi.org/10.1055/s-0034-1385816
Published online: 29.1.2015
Fortschr Röntgenstr 2015; 187: 276–282 © Georg Thieme Verlag KG Stuttgart · New York · ISSN 1438-9029

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Abstract

Purpose: Analysis, evaluation and classification of hepatic arterial supply variants and determination of their frequency distribution in CT-angiographies.
Materials and Methods: CT-angiographies of 1,568 patients were evaluated retrospectively for the period between January 1, 2010 and August 30, 2012. The hepatic arterial anatomy was assessed and categorized according to Michels's classification. So far unclassified variants were considered separately.
Results: CT-angiographies of 1297 patients were included in the study. Type I according to Michels was seen in 937 cases (72.2 %), followed by type V in 114 patients (8.8 %) and type III in 83 patients (6.4 %). Type X could not be found in any of the patients. Not yet classified variants were discovered in 26 patients. The most frequent variant in this connection was a right hepatic artery originating from the superior mesenteric artery with the left hepatic artery originating from the left gastric artery (n = 10).
Conclusion: Michels's classification could be largely confirmed on the basis of a radiologically examined patient population. Not yet classified variants were categorized into subgroups of the existing classification.
Key points:
- Imaging of hepatic arterial supply variants using CT-angiography
- Distribution of variations of arterial liver supply in a general patient population
- Expansion of Michels's classification to include new variations of the arterial liver supply

Citation Format:
- Löschner C, Nagel SN, Kausche S et al. Hepatic Arterial Supply in 1297 CT-Angiogra-

Zusammenfassung

Ziel: Analyse, Auswertung und Klassifikation von Varianten der arteriellen Leberversorgung und die Bestimmung deren Häufigkeitsverteilung in CT-Angiografien.
Material und Methoden: Die CT-Angiografien von 1568 Patienten wurden für den Zeitraum zwischen 1.1.2010 und 30.8.2012 retrospektiv ausgewertet. Die arterielle Leberversorgung wurde untersucht und entsprechend der Klassifikation nach Michels eingeteilt. Bisher nicht klassifizierte Varianten wurden gesondert berücksichtigt.
Ergebnisse: Die CT-Angiografien von 1297 Patienten konnten in die Studie eingeschlossen werden. Typ I nach Michels fand sich in 937 Fällen (72,2 %), gefolgt von Typ V bei 114 Patienten (8,8 %) und Typ III bei 83 Patienten (6,4 %). Einzig Typ X konnte bei keinem Patienten gefunden werden. Bei 26 Patienten wurden bisher nicht klassifizierte Varianten gefunden. Die häufigste Variante hierbei war eine Arteria hepatica dextra mit Ursprung aus der Arteria mesenterica superior bei Ursprung der Arteria hepatica sinistra aus der Arteria gastrica sinistra (n = 10).
Schlussfolgerung: Die Klassifikation von Michels konnte anhand eines radiologisch untersuchten Patientenkollektivs weitgehend bestätigt werden. Bisher unklassifizierte Varianten wurden in Untergruppen in die bestehende Klassifikation eingeordnet.

Introduction

The hepatic arterial supply and its variability play an important role, particularly in liver transplantation and living donor liver transplantation. In the Eurotransplant area, 18 151 postmortal liver transplantations were performed between 2002 and 2013 [1]. Of course, precise knowledge of variants of the hepatic

arterial supply is essential. Vascular complications can, for example, lead to insufficient blood flow to the liver with subsequent transplant loss [2 – 4]. Moreover, in hepatic tumor embolizations [5, 6] as well as in extrahepatic abdominal surgeries involving the stomach, pancreas or gall bladder [7 – 9], variants of the hepatic vascular supply can present anatomical problems.
Currently, CT-angiography is the diagnostic standard for preoperative and pre-interventional assessment of the hepatic arterial anatomy. Commonly Michels's classification is used for a precise description [10]. N. A. Michels performed 200 autopsies for his study and categorized variants of the hepatic arterial supply into 10 different types. His classification was modified by Hiatt in 1994 [11], who analyzed 1000 medical records and classified variants into 6 categories. Other important publications came from Saba et al with 1600 patients [12], Covey et al. with 600 patients [13] and Koops et al. with 604 patients [14], who all largely followed Michels's classification. Further studies in recent years have come from Sureka et al. with 600 patients [15], Song et al. with 5002 patients [16], Abdullah et al. with 932 patients [17], Gruttadauria et al. with 701 patients [18] and Soin et al. with 527 patients [2]. All of these studies, however, developed their own classifications without derivation from Michels's classification. Therefore, the comparability is limited.
The purpose of this study was the analysis, evaluation and classification of hepatic arterial supply variants and the determination of their frequency distribution in CT-angiographies.

Materials and Methods

At a university hospital, all CT-angiographies covering the abdomen were analyzed retrospectively between January 1, 2010 and August 30, 2012. The hospital comprises a liver transplant center and radiologists are trained on the evaluation of liver anatomy. Therefore, deviations of the hepatic arterial anatomy are usually reported regardless of the indication for the examination. S.N and S. K. (> 3 years and > 1 year of experience, respectively) performed most of the included examinations themselves and wrote the later considered reports, paying special attention to the liver anatomy. The reports were verified by U. T. (> 15 years of experience), again with a special focus on the hepatic arterial supply.
C. L. conducted a blinded re-evaluation of all CT examinations and compared his results to the radiological reports. Additionally, C. L. and S. N. together re-evaluated all variants other than type I. Any discrepancies were resolved by consensus in consultation with U. T. The assessment of the hepatic arterial supply was thus redundant.
Out of 1568 CT-angiographies, 1297 could be included in this study (**Table 1**). Only one CT-angiography per patient was used. In patients with multiple CT-angiographies, only pre-operative and pre-interventional examinations were considered and the scan with the best quality was chosen. 271 patients were excluded, mainly because of iatrogenic or disease-related changes in the vascular supply, i. e. status post total or split liver transplantation, hemihepatectomy, Whipple or Billroth I & II procedure, vascular interventions (e. g. mesenteric or celiac artery bypass, transcatheter arterial chemoembolization (TACE)) or aortic dissection (Stanford A/B). Patients with a transjugular intrahepatic portosystemic shunt (TIPS) were excluded as a precaution because of potential artifacts that could impair the detection especially of smaller vessels. 9 CT-angiographies were excluded because of poor image quality.
Written informed consent to the CT scan and contrast application also included optional consent to anonymous use of imaging data and was given for each of the included examinations. The local ethical committee approved the study.

Table 1 Patient demographics.

sex	number	percentage	∅-age in years (min. – max.)
male	797	61.45	61.64 (20 – 102)
female	500	38.55	61.63 (20 – 92)
total	1,297	100	61.74

CT-Angiography

All images were acquired with a 64-slice CT scanner (2005 GE LightSpeed VCT 64 Slice CT, GE Healthcare, Milwaukee, WI, USA). A standardized scanning protocol was used: arterial phases were timed using bolus tracking with a monitoring delay of 7 s for scans starting in the abdomen, 3 s for scans starting in the chest. A monitor interscan delay of 3 s and a diagnostic delay of 3 s were used. The scan triggered when a threshold of Δ100-HU in the thoracic or abdominal aorta was reached. The dose of the contrast agent (Ultravist 300; Bayer Schering Pharma, Berlin, Germany) was adjusted according to the type of CT-angiography (usually 100 ml for abdominal scans, 120 ml for combined thoracoabdominal scans); flow speed was typically 4 ml/s. Contrast injection was followed by an NaCl flush (40 ml). Images were acquired with a primary slice thickness of 0.625 mm, a table speed of 39.37 mm/s and a pitch of 0.984:1. Multiplanar reconstructions (axial, coronal and sagittal) with a standardized slice thickness of 3 mm were sent to the picture archiving system and used for the evaluation. Image review was done using our standard workstation (PACS: Cerner ProVision, Cerner Corporation, Kansas City, MO, USA; RIS: Lorenzo RadCentre, iSoft Health GmbH, Mannheim, Germany) with high-resolution displays (Model MDCC 2121, Barco N. V., Kortrijk, Belgium). Patients never received oral contrast prior to the scan.

Classification

The classification of the hepatic arterial supply was based on Michels's classification [10] (**Fig. 1**). Not yet classified variants were assigned to the most suitable type and recorded in an extended classification. We also used a) and b) subtypes for these variants as Michels did with type VIII. The arterial supply of the left hepatic lobe from the left hepatic artery (LHA) and of the right hepatic lobe from the right hepatic artery (RHA) was considered the textbook type (Michels type I). Both arteries derive from the proper hepatic artery, which is the continuation of the common hepatic artery (CHA) after the gastroduodenal artery (GDA)

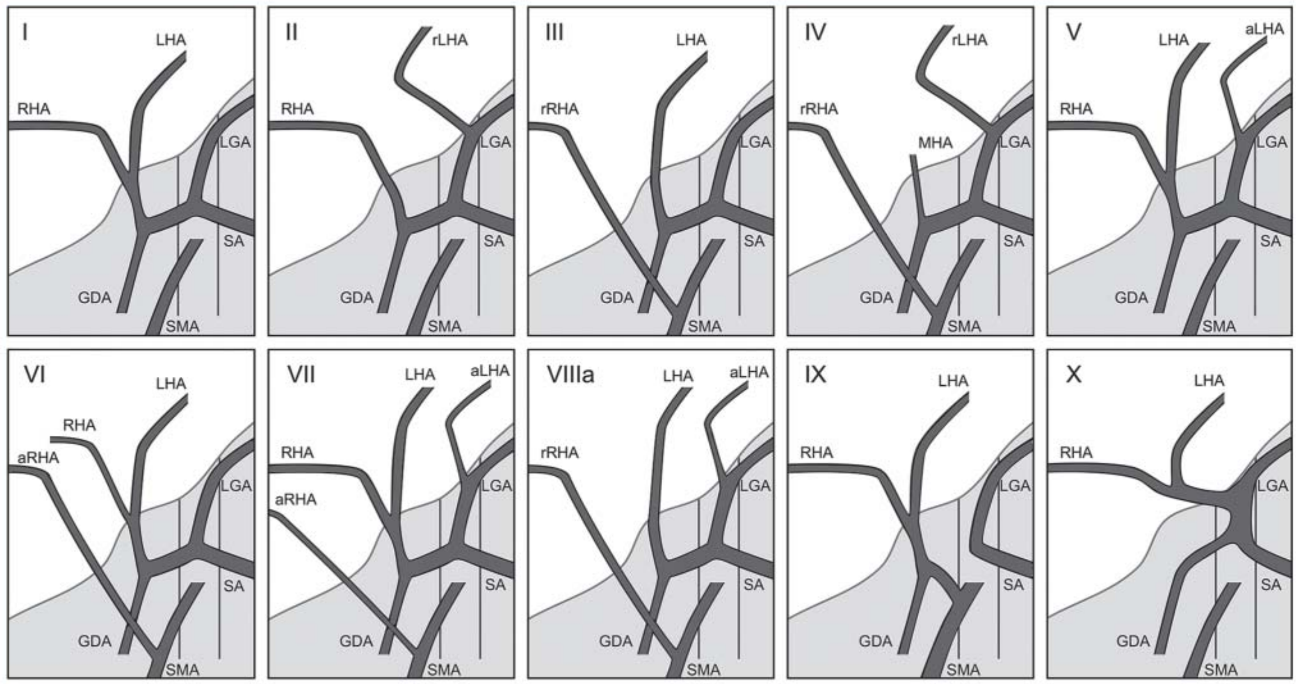

Fig. 1 Schematic illustrations of Michels's classification of hepatic arterial supply variants with types I-X. Legend: LHA = left hepatic artery, RHA = right hepatic artery, GDA = gastroduodenal artery, LGA = left gastric artery, SA = splenic artery, aLHA = accessory left hepatic artery, rLHA = replaced left hepatic artery, aRHA = accessory right hepatic artery, rRHA = replaced right hepatic artery, MHA = middle hepatic artery. Note: only type VIIIa shown, type VIIIb corresponds to the inverted case with an aberrant LHA from the LGA with an accessory RHA from the SMA.

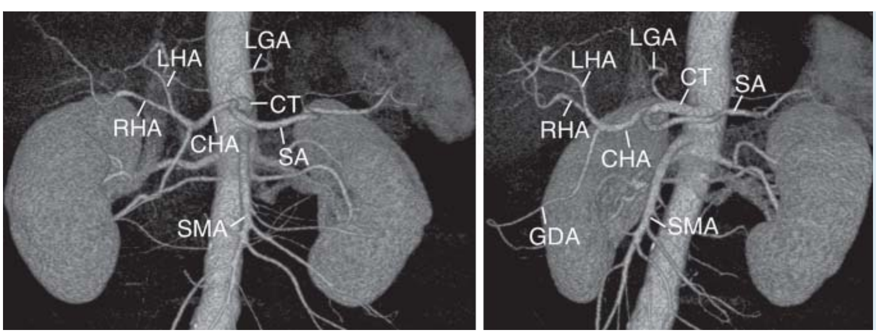

Fig. 2 3D-reconstruction showing Michels type I (textbook type). Legend: LHA = left hepatic artery, RHA = right hepartic artery, CHA = common hepatic artery, CT = celiac trunk, LGA = left gastric artery, SA = splenic artery, SMA = superior mesenteric artery. Note: accessory renal arteries bilaterally

branches off (▶ **Fig. 2**). Variants of the arterial supply result from arteries that originate from the superior mesenteric artery (SMA), from the left gastric artery (LGA) or directly from the aorta (▶ **Fig. 3**). They can either exist in addition to the vessels of the textbook type or replace them completely. If a double arterial supply of a hepatic lobe was identified, the vessel was classified as accessory, whereas if the supply occurred exclusively through one vessel, it was marked as aberrant (replaced). This declaration, however, can be misleading, since all arteries are end arteries with a selective distribution to a definite area of the liver [10].

Results

According to Michels's classification, 937 cases (72.2 %) showed the textbook type (type I). In 360 patients (27.8 %), deviations from the normal supply were identified, including 26 (2.0 %) patients with not yet classified variants. The overall second most frequent variant was an accessory LHA from the LGA (type V, n = 114, 8.8 %), followed by an aberrant RHA from the SMA (type III, n = 83, 6.4 %) and an aberrant LHA from the LGA (type II, n = 55, 4.2 %). A complete overview of all variants is provided in ▶ **Table 2.**

The complete outflow of the CHA from the LGA (type X) could not be found in any of the examined patients. Out of the 26 patients with non-classified supply types, the most frequent variant was an aberrant RHA originating from the SMA, with an aberrant LHA originating from the LGA as in type IV, but without the middle hepatic artery (MHA) (new as type IVa) (n = 10, 0.8 %). In four cases (0.3 %) we found a modification showing the SMA and the celiac trunk (CT) forming a common trunk, a so-called celiacomesenteric trunk, with a subsequent normal blood supply of the liver from the CHA (new as type Ia). In another four cases (0.3 %) we found a modification of type V with the CHA originating directly from the aorta (new as type Va). Three patients (0.2 %) showed a separate origin of the RHA and the LHA

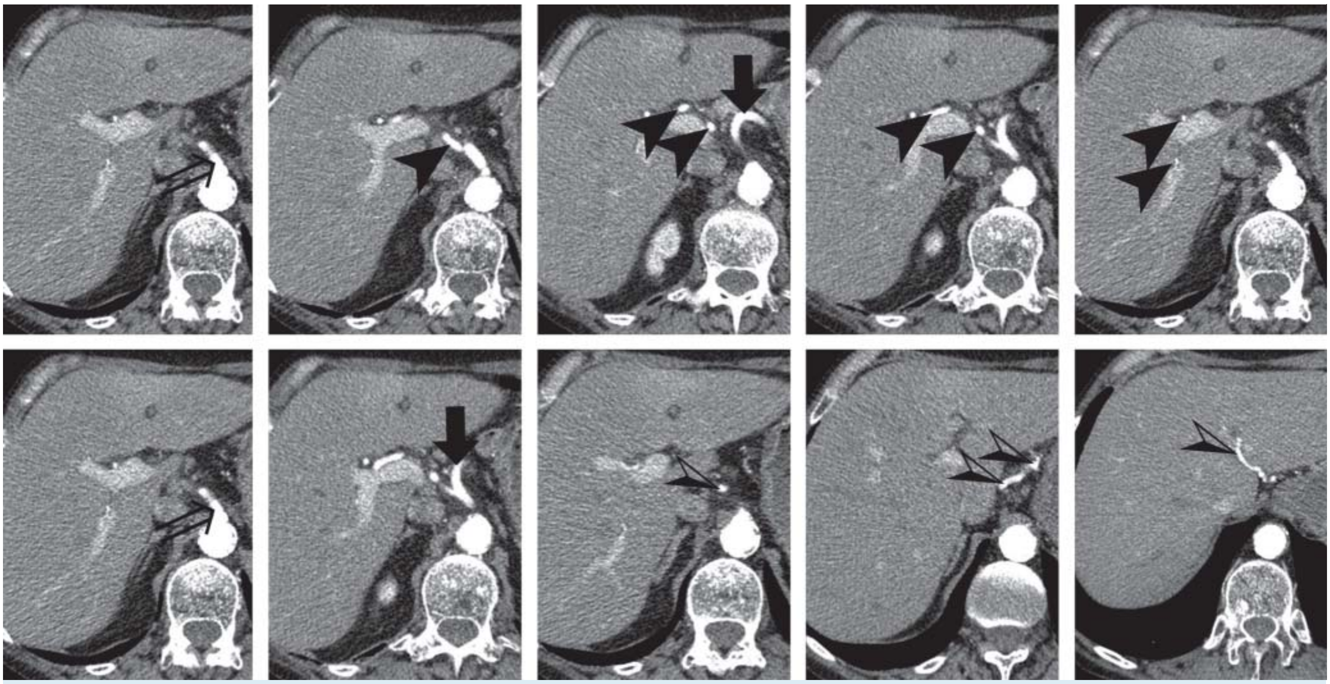

Fig. 3 Series of axial reconstruction slices showing Michels type 2. Legend: Top row shows tracking of the right hepatic artery, bottom row shows tracking of the replaced left hepatic artery. Open arrow = celiac trunk, black arrowhead = common hepatic artery continuing as proper hepatic artery when the gastroduodenal artery branches off and finally as the right hepatic artery, thick arrow = splenic artery, black and white arrow head = left gastric artery continuing as replaced left hepatic artery

Table 2 Distribution of the found variants

Michels type		n	%
I		937	72.2
II		55	4.2
III		83	6.4
IV		20	1.5
V		114	8.8
VI		20	1.5
VII		6	0.5
VIII		11	0.8
IX		25	2.0
X		0	0
not yet classified types		**n**	**%**
Ia:	SMA+CT = 1 truncus	4	0.3
IIa:	CHA from aorta	1	0.1
IIb:	LGA from aorta	1	0.1
IIIa:	CHA from aorta	2	0.2
IVa:	no MHA	10	0.8
Va:	CHA from aorta	4	0.3
VIIa:	aRHA from aorta	1	0.1
XI:	RHA+LHA separated from CT	3	0.2

SMA = superior mesenteric artery, CT = celiac trunk, CHA = common hepatic artery, LGA = left gastric artery, MHA = middle hepatic artery, aRHA = accessory right hepatic artery, RHA = right hepatic artery, LHA = left hepatic artery

from the CT (new as type XI). Two patients (0.2 %) had an aberrant RHA from the SMA as in type III with the CHA originating directly from the aorta (new as type IIIa). Three variants could be detected only once (0.1 %): type VII with an accessory RHA arising directly from the aorta (new as type VIIa), type II with the CHA arising directly from the aorta (new as type IIa) and type II with the LGA arising directly from the aorta (new as type IIb) (**Fig. 4**).

Discussion

In the past few years, CT-angiography has increasingly been used to get an overview of the vascular situation prior to surgeries and angiographic interventions. Today it is the diagnostic standard for pre-operative and pre-interventional evaluation of the hepatic vascular supply. Advantages are, for example, the possibilities of 2 D and 3 D image reconstructions. Varying image qualities due to artifacts as well as patient and scanner characteristics can be a disadvantage for a standardized evaluation. Furthermore, the slice thickness of reconstructions and anatomical cross-sections of the vessels play a role during the assessment. For example, several studies have shown the benefit of conventional angiography in the detection of smaller intrahepatic vessels, aberrant arteries or the LGA [19 – 21]. However, these studies compared conventional angiographies to CT-angiographies with rather large slice reconstructions between 8 and 10 mm. When compared to CT-angiographies with thinner slice thicknesses, a good correlation of both imaging modalities was seen in newer studies and CT-angiography was found to be sufficient to evaluate the hepatic arterial anatomy [22 – 27].
The importance of precise knowledge of the hepatic arterial anatomy is evident when vascular complications are considered. In liver transplantations these typically include stenosis and hepatic artery occlusions, steal-syndromes and aneurysms [28]. Currently, the incidence of vascular complications is documented with a rate of 0.7 % to 12.9 % [4, 28, 29]. For the TACE procedure Maeda et al. reported that the incidence for arterial injuries in this connection is up to 16 % for each artery and up to 48 % for each patient [30]. Moreover, in extrahepatic surgeries or interventions invol-

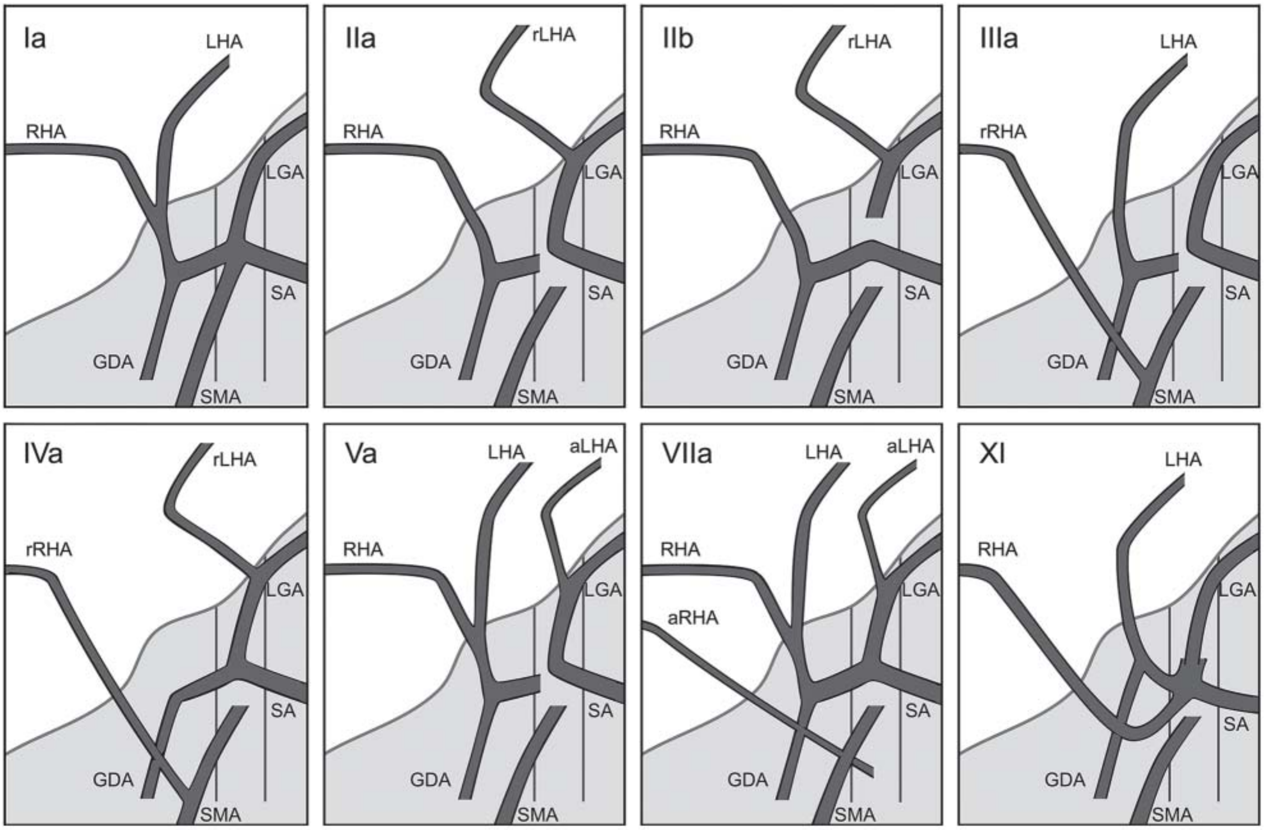

Fig. 4 Schematic illustrations of newly discovered types of hepatic arterial supply. Legend: LHA = left hepatic artery, RHA = right hepatic artery, GDA = gastroduodenal artery, LGA = left gastric artery, SA = splenic artery, aLHA = accessory left hepatic artery, rLHA = replaced left hepatic artery, aRHA = accessory right hepatic artery, rRHA = replaced right hepatic artery

ving the stomach, esophagus or pancreas [8, 31, 32], vascular variants can lead to unexpected bleeding or an impairment of the hepatic arterial supply.

One explanation for the unequal gender distribution in the study population could be that many diseases of civilization preferentially affect men (e.g. cardiovascular, hepatobiliary or malignant diseases) [33 – 35].

In our study the textbook type (type I) was found in 72.2 % of cases, which is in line with the results of other studies using CT-angiography or conventional angiography for the evaluation [2, 14]. In the literature, the data vary across autoptic and radiological studies from 55 % to 79 % (**Table 3**). Possible reasons for these fluctuations could be the inclusion and exclusion criteria, the case number or the evaluation method (autopsy/CT-angiography/conventional angiography; CT slice thickness).

The middle hepatic artery (MHA) described by Michels was not further considered, because it originates from the LHA or RHA except for type IV [10]. Wang et al. reported that the MHA exists in 71 % of the patients, regardless of the hepatic arterial supply and derives directly or indirectly from the normal or a replaced CHA [36].

Our results were close to those documented for conventional angiographies, the actual gold standard for vascular diagnostics, and furthermore widely match the results concerning the distribution of accessory and replaced vessels. Depending on the study, variations other than the textbook type were between 12 % and 49 % [7, 11, 31, 37, 38]. In our study the proportion was 27 %. The two most frequent variants were an accessory LHA from LGA (type V) with 8.8 % and a replaced RHA from the SMA (type III) with 6.4 %. In Michels's study, type III ranked second (11 %), type II ranked third (10 %) and type V (8 %) came in fourth. It was conspicuous that the percentage of replaced vessels found by Michel was higher (type II and III). Two divergent pictures emerged concerning the distribution of the accessory vessels (type V and VI): while our results for type V corresponded approximately to those of Michels (8.8 % vs. 8.0 %), the results for type VI differed clearly (1.5 % vs. 7.0 %) [10]. The evaluation of other studies [39, 40] also revealed that the number of accessory vessels was less than that found by Michels. According to Koops et al., accessory arteries might be underrepresented in studies with CT-angiographies because of their partly very small size, or because the differentiation between replaced and accessory vessels might be limited [14]. The complete origin of the CHA from the LGA (type X) could not be found in any patient, which corresponds to the studies of Koops et al. and Covey et al. [13, 14].

In 26 patients not yet classified variants were detected. This result did not meet the expectations, since their incidence in other studies was higher. These unclassified variants mostly affected the origin of the vessels from the celiac trunk. In order to take them into account, they were categorized into subgroups of the existing classification (**Table 4**).

Table 3 Comparison with results of other studies.

variants	own results n = 1297 CT-angio	Michels [9] n = 200 autopsy	Koops et al. [13] n = 604 angio	Covey et al. [12] n = 600 angio	Saba et al. [11] N = 1629 CT-angio
type I	72.2 %	55.0 %	79.1 %	61.3 %	61.4
type II	4.2 %	10.0	2.5	3.8	7.5
type III	6.4 %	11.0	8.6	8.7	10.6
type IV	1.5 %	1.0	1.0	0.5	1.3
type V	8.8 %	8.0	0.5	10.7	6.7
type VI	1.5 %	7.0	3.3	1.5	6.9
type VII	0.5 %	1.0	0.2	1.0	0.7
type VIII	0.8 %	2.0	0.2	3.0	1.9
type IX	2.0 %	4.5	2.8	2.0	1.6
type X	0	0.5	0	0	0.3
other	2.0 %	0	1.8	7.5	1.1

Tab. 4 Modified classification including so far unclassified variants.

type I: LHA + RHA from CHA from CT
– type Ia: LHA + RHA from CHA, CT + SMA from 1 common trunk
type II: rLHA from LGA + RHA from CHA
– type IIa: rLHA from LGA + RHA from CHA, CHA from aorta
– type IIb: rLHA from LGA from aorta, RHA from CHA
type III: LHA from CHA + rRHA from SMA
– type IIIa: LHA from CHA from aorta + rRHA from SMA
type IV: rLHA from LGA + rRHA from SMA + MHA from GDA
– type IVa: rLHA from LGA + rRHA from SMA without MHA
type V: LHA+RHA from CHA + aLHA from LGA
– type Va: LHA + RHA from CHA from aorta + aLHA from LGA
type VI: LHA+RHA from CHA+ aRHA from SMA
type VII: LHA+RHA from CHA + aLHA from LGA + aRHA from SMA
– type VIIa: LHA + RHA from CHA + aLHA from LGA + aRHA from aorta
type VIIIa: LHA from CHA + aLHA from LGA + rRHA from SMA type VIIIb: rLHA from LGA + RHA from CHA + aRHA from SMA
type IX: LHA + RHA from CHA from SMA
type X: LHA + RHA from CHA from LGA
type XI: LHA + RHA divided from CT

LHA = left hepatic artery, RHA = right hepatic artery, CHA = common hepatic artery, CT = celiac trunk, SMA = superior mesenteric artery, rLHA = replaced left hepatic artery, rRHA = replaced right hepatic artery, GDA = gastroduodenal artery, LGA = left gastric artery, aLHA = accessory left hepatic artery, aRHA = accessory right hepatic artery, MHA = middle hepatic artery. Note: type VIII as already subdivided by Michels into a/b subgroups.

Clinical relevance

- The results of other studies regarding the distribution of hepatic artery variants could be widely confirmed.
- 8 not yet classified subtypes were found.
- The detected, but not yet represented variants were integrated into Michels's classification.

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