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## The “Vessel through Strait” Sign is a Signature Radiological Sign for the Diagnosis of Left Hepatic Artery Variation

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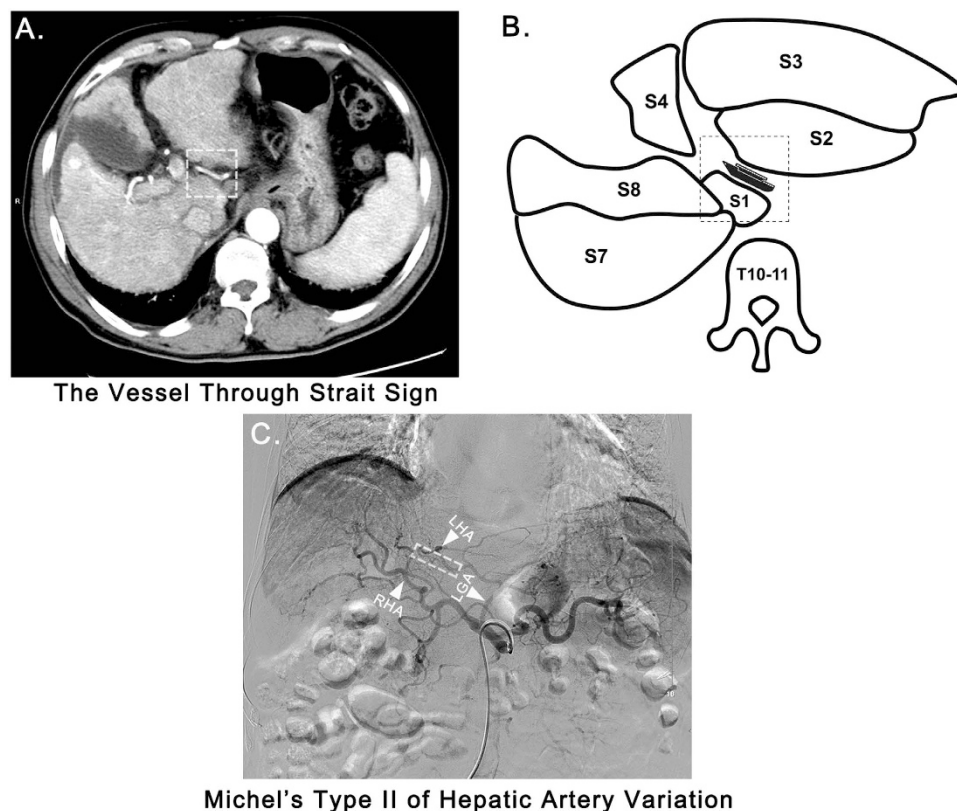
An aberrant artery (AA) can frequently be observed coursing through the fissure for the ligamentum venosum (FLV) which was termed the “vessel through strait” sign (VTSS) by us. Fundamental data including the incidence, anatomical composition and clinical significance of VTSS and the AAs composing VTSS are still lacking. We sought to give a systematic demonstration on this issue in the present study. VTSS was respectively analyzed in 2,275 patients and was observed in 357 of them. Interestingly, 319 (89.4%) out of the 357 patients exhibiting VTSS were proved to have left hepatic artery variation (LHAV) (247 with replaced left hepatic artery, 64 with accessory left hepatic artery and 8 with variant common hepatic artery). We therefore hypothesized that VTSS could be a sign that strongly associated with LHAV and could be used for its diagnosis. In the following validating analysis, VTSS gained a sensitivity of 96.3% and a specificity of 98.3% for the diagnosis of LHAV in another bicenter cohort consisted of 1,329 patients. In conclusion, VTSS is a signature radiological sign of LHAV which could be used as an easy and specific method for the diagnosis of LHAV.

An aberrant artery (AA) can be frequently observed coursing through the fissure for the ligamentum venosum (FLV) on axial contrast-enhanced computed tomography (CT) or magnetic resonance imaging (MRI) scans (Fig. 1-A). We termed this manifestation the “vessel through strait” sign (VTSS), as the AA highly resembles a “vessel” which is sailing through a “strait” composed of segment I (S1) and segment II (S2) of the liver (Fig. 1-B). VTSS is estimated to be observed in approximately 15–20% of the general population according to our experience, however, despite being sparsely described as the variant left hepatic artery (LHA)<sup>1,2</sup>, or variant common hepatic artery (CHA)<sup>3</sup> or accessory left gastric artery (LGA)<sup>4</sup>, current knowledge about VTSS and the AAs composing VTSS is very limit, fundamental data including its incidence, anatomical composition and clinical significance are lacking. To address this issue, in the present study, we respectively analyzed the hepatic arteriographic and CT/MRI data in 2,275 patients receiving transcatheter arterial chemoembolization (TACE) with a particular focusing on the VTSS. A very interesting result of our analysis was that nearly 90% of the patients exhibiting VTSS were proved to have left hepatic artery variation (LHAV). The strong association between VTSS and LHAV naturally drove us to propose and validate the hypothesis that VTSS is a signature radiographic sign of LHAV that could be used for its diagnosis.

LHAV include type II, IV, V, VII, VIII and X of Michel’s classification of hepatic artery variation (HAV)<sup>5</sup>, which occur in approximately 12–22% of the general population and represent the second most common pattern of HAV<sup>5–7</sup>. Preoperative awareness of LHAV is therefore important for the planning and performance of all of the surgical or radiological interventional procedures arranged in the left hepatic lobe. Currently, hepatic artery

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**Figure 1.** (A) A typical VTSS (white dashed square) formed by a replaced LHA entering liver through FLV was seen in the arterial phase of a contrast-enhanced CT scan. (B) A schematic diagram of VTSS. The vessel represents the aberrant artery, which is sailing through a “strait” composed of S1 and S2 of the liver (C) The patient was confirmed to have a replaced LHA arising from LGA (Michel's type II HAV) by DSHA. The corresponding part of the replaced LHA forming VTSS was highlighted by the white dashed rectangle. LHA, left hepatic artery; LGA, left gastric artery; RHA, right hepatic artery; S, segment of the liver; T, thoracic vertebrae.

Artery in VTSS	Cases	Percentage	Blood Direction
Replaced LHA	247	69.1%	Entering liver
Accessory LHA	64	17.9%	Entering liver
Variant CHA	8	2.2%	Entering liver
Accessory LGA	25	7.0%	Leaving liver
LIPA	3	0.8%	Leaving liver
Accessory LGA & LIPA	10	3.0%	Leaving liver
Total	357	100%	Entering liver (89%) Leaving liver (11%)

**Table 1. Anatomical compositions of the aberrant arteries seen in VTSS.** LHA, left hepatic artery; CHA, common hepatic artery; LGA, left gastric artery; LIPA, left inferior phrenic artery.

variations (HAVs) including LHAV are mainly detected by digital subtraction hepatic arteriography (DSHA) or computed tomographic angiography (CTA). However, DSHA is invasive and cannot be used preoperatively, whereas CTA requires an additional reconstruction procedure that might require extra time and expense and is not routinely applied to all patients. Thus, clinical application of VTSS may provide an easy and specific solution for the non-invasive diagnosis of LHAV. For this purpose, we conducted a validating analysis to evaluate the usefulness of VTSS as a diagnostic sign of LHAV in another bicenter series of 1,329 patients.

## Results

**The incidence of VTSS and the anatomical compositions of the AAs seen in VTSS.** The presence of VTSS was screened in a training cohort of 2,275 patients and was identified in 357 (15.7%) of them. Representative images of VTSS are shown in Fig. 1 and the supplementary figures. In each patient with VTSS, the anatomical property of the observed AA was further analysed according to the hepatic arteriography data.

Type	Cases (n, %)	VTSS positive (n, %)	Description
<b>Left Hepatic Artery Variation (n = 324, 14.2%)</b>			
II	193 (8.5%)	192(94.4%)	Replaced LHA from LGA
IV	50 (2.2%)	49 (98%)	Replaced RHA and LHA
V	58 (2.5%)	55 (94.8%)	Accessory LHA
VII	0 (0%)	0 (0%)	Accessory RHA and LHA
VIII	9 (0.4%)	9 (100%)	Replaced RHA and Accessory LHA
	6 (0.3%)	6 (100%)	Replaced LHA and Accessory RHA
X	8 (0.4%)	8 (100%)	CHA from LGA
<b>Normal Anatomy (n=1,566, 68.8%)</b>			
I	1,566 (68.8%)	34 (2.2%)	Normal
<b>Right Hepatic Artery Variation and others (n = 385, 17.0%)</b>			
III	123 (5.4%)	2 (1.6%)	Replaced RHA from SMA
VI	13 (0.6%)	0 (0%)	Accessory RHA
IX	80 (3.5%)	0 (0%)	CHA from SMA
NC	169 (7.4%)	2 (1.14%)	Not classifiable
Total	2,275(100%)	357(15.7%)	

**Table 2. The globe profile of HAV in 2,275 patients and the incidence of VTSS according to Michel's classification of HAV.** LHA, left hepatic artery; CHA, common hepatic artery; LGA, left gastric artery; RHA, right hepatic artery; SMA, superior mesenteric artery; NC, not classifiable.

<b>Center I (n = 962)</b>		
	Real LHAV (n = 147)	Real Non-LHAV(n = 815)
VTSS positive	144	12
VTSS negative	3	803
<b>Center II (n = 543)</b>		
	Real LHAV (n = 69)	Real Non-LHAV(n = 474)
VTSS positive	64	10
VTSS negative	5	464
Overall sensitivity	$208/216 \times 100\% = 96.3\%$	
Overall specificity	$1267/1289 \times 100\% = 98.3\%$	
Overall PPV	$208/230 \times 100\% = 90.4\%$	
Overall NPV	$1267/1275 \times 100\% = 99.4\%$	

**Table 3. The sensitivity and specificity of VTSS for the diagnosis of LHVA.** PPV, positive predict value; NPV, negative predict value.

As shown in Table 1, the anatomical composition of the VTSS-associated AA was as follows: replaced LHA (n = 246, 68.9%, Fig. 1-C), accessory LHA (n = 64, 17.9%, supplementary fig. 1), common hepatic artery (CHA) (n = 8, 2.2%, supplementary fig. 2), accessory LGA (n = 26, 7.3%, supplementary fig. 3), left inferior phrenic artery (LIPA) (n = 3, 0.8%, supplementary fig. 4) and the common trunk of accessory LGA and LIPA (n = 10, 2.9%, supplementary fig. 5). Thus, in total, 89.1% (318/357) of the patients with VTSS do indeed have LHAV. We further demonstrated the prevalence of VTSS in all of the 2,275 patients according to their Michel's classification results. The global profile of HAV in the 2,275 patients and the incidence of VTSS of each Michel's classification type are shown in Table 2. Overall, LHAV was detected in 318 (14.1%) patients, and VTSS was observed in 312 (98.1%) of them.

**The usefulness of VTSS as a diagnostic sign of LHAV.** Our analysis indicated that VTSS was strongly associated with LHAV and might be a signature radiological sign of LHAV. The usefulness of VTSS as a diagnostic sign of LHAV was then evaluated in another bicenter validating cohort of 1,346 patients. As shown in Table 3, in total, VTSS was detected in 230 (16.1%) patients, of whom 208 (90.4%) were confirmed to have LHAV. There were 22 patients who were positive for VTSS but not LHAV, and 8 patients had LHVA but did not exhibit VTSS. Thus, the overall sensitivity, specificity, positive and negative predictive value of VTSS for predicting LHAV were 96.3%, 98.3%, 90.4% and 99.4%, respectively.

We further demonstrated if the slice thickness of scan could affect the recognition of VTSS. We analyzed all the 108 patients whose VTSS was found by CT scan in the validating cohort. The CT thickness was set to 1.25 mm, 2.5 mm, 5 mm and 7 mm, respectively and VTSS was recognized in all patients at all thicknesses (data not shown).

## Discussion

This study is the first systematic analysis, to our knowledge, focusing on the AA courses through FLV. Our results demonstrated that the manifestation of AA in FLV occurred in approximately 15% of the patients receiving TACE. Anatomically, these AAs heterogeneously consisted of at least six different arteries, namely replaced LHA, accessory LHA, CHA, accessory LGA, LIPA and the common trunk of accessory LGA and LIPA, more importantly, 90% of the AAs seen in FLV were either replaced or accessory LHA originating from the LGA. The above finding strongly indicated that VTSS is a signature radiological sign of LHAV.

The VTSS we presented in this study provided an easy, specific and cost effective method for preoperative awareness of LHAV, which might substantially reduce the risk of complications caused by the ignorance of variant arteries. By recognizing VTSS, radiologists might take into account the high possibility of LHAV and be prepared when dealing with unexpected situations caused by aberrant LHA during TACE procedures.

Another important finding of our study is that the FLV seems to be the only portal for the aberrant arteries to either enter or leave the left hepatic lobe, considering the incidence of observing an aberrant artery in this area could be as high as 15%. FLV appears to be a critical anatomical structure that should receive more attention not only from radiologists but also from surgeons. We highly suggest radiologists and surgeons carefully observe the FLV on contrast-enhanced CT or MRI before all procedures, and when VTSS is found, essential preparations should be considered and arranged. In patients who will receive left-hepatic related procedures, further examination such as CTA might be required to obtain a more detailed profile of the hepatic arteries.

Our study had several limitations. First, we used both CT and MRI image for various diagnostic purposes to determine the presence of VTSS, and this lack of consistency might impact the precise evaluation of the whole system. Second, VTSS is generally a subjective judgment in this present study that could be influenced by a doctor's experience and multiple other factors, and a quantitative definition of VTSS in the future will provide a solution to this issue. Third, about 10% of patients with VTSS do not exhibit LHAV, although we had some preliminary experiences such as the non-LHAV arteries were usually thinner and shorter in VTSS, our current method was not able to distinguish them from those that do exhibit LHAV.

In conclusion, in this study, we described an interesting radiological sign—the VTSS. By analysing the anatomical composition of the AA composing VTSS in a large-scale series of 2,275 patients, we established and validated a strong association between VTSS and LHAV. As a signature radiological sign, VTSS showed a sensitivity of 96.3% and a specificity of 98.3% for the diagnosis of LHAV. Finally, it has to be pointed out that despite being useful, VTSS could only be complementary tool but not a replacement of CTA, with particular usefulness in cases when CTA is not available.

## Materials and Methods

The study protocol was reviewed and approved by the institutional review board (IRB) of the 302 Hospital, Beijing, China and the general hospital of PLA, Beijing, China. Written informed consent was waived by the IRB of both hospitals because this is an observational retrospective study and all of the data used were acquired for diagnostic or therapeutic purposes and were generated before the study was designed.

**Patients.** Between August 2012 and August 2013, 2,275 patients with hepatocellular carcinoma (HCC) on whom TACE was performed at the 302 hospital, Beijing, China were enrolled as the training cohort for analysing the incidence and anatomical compositions of the AAs seen in VTSS. To validate the usefulness of VTSS as a potential diagnostic sign of LHAV, 962 and 543 patients with HCC that received TACE between September 2013 and March 2014 at the 302 hospital and the general hospital of PLA, respectively, were enrolled to generate a bicenter validating cohort. All of the patients in the training and validating cohort had complete analysable hepatic arteriography data and received a contrast enhanced scan by either CT or MRI before TACE. Data from the training cohort were analysed by two independent radiologists (Y.L. and X.W.) and were confirmed by a third when their judgments were in conflict (Q.Y.). Data from the validating cohort were analysed blindly by another two independent radiologists (Z.W. and J.D.).

**Hepatic Arteriography and TACE Procedure.** TACE was performed as previously described<sup>7</sup>. After local anaesthesia, the femoral artery was accessed using the standard Seldinger technique. A 5-F RH catheter was then conducted, through which arteriography of the celiac trunk, superior mesenteric artery (SMA) and hepatic arteries were successively performed to collect the overview of the hepatic arterial blood supply and the location of HCC. Upon the identification of HCC and its tumor feeding artery, a 3-F microcatheter was coaxially inserted through the 5-F RH catheter into the tumor feeding artery for superselective embolization with an emulsion of lipiodol and cytotoxic drugs.

**CT and MRI Scan.** Contrast-enhanced CT and/or MRI scans of the abdomen were performed in all patients for various diagnostic purposes. CT scan was performed by a GE Light-speed VCT 64 slice scanner (GE Healthcare, Milwaukee, WI, USA). MRI scan was performed by a GE Signa HDx 1.5T scanner or a GE Signa HDx 3.0T scanner (both from GE Healthcare, Milwaukee, WI, USA). The scans followed the protocol for standard contrast-enhanced abdominal CT or MRI examination as previously described<sup>8–10</sup>. The slice thickness was 1.25 mm, 2.5 mm, 5 mm, and 7 mm, respectively, for determining the effects of slice thickness on the recognition of VTSS and was 5 mm for both CT and MRI in other analysis.

**Image Analysis and the Definition of VTSS and LHAV.** VTSS was defined as the recognition of an enhanced vessel coursing through the FLV in the arterial phase of an axial CT or MRI scan at the level of the 10<sup>th</sup> or 11<sup>th</sup> thoracic vertebrae. Typical manifestations of VTSS were depicted in Fig. 1 and supplementary Figs 1–5. For patients with VTSS, the anatomical property of the aberrant artery in VTSS was further analysed. LHAV was

evaluated based on the hepatic arteriography data and was classified as type I to type X according to Michel's classification<sup>5</sup>. LHAV was defined as patients with a replaced or accessory LHA or a common hepatic artery (CHA) originating from the LGA, i.e., Michel's type II, IV, V, VII, VIII and X.

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## Author Contributions

G.R., Y.L. and Y.L. designed the study and wrote the main manuscript text. Z.W., X.W., Q.Y., L.Z., H.W., J.Z., J.D. W.M., W.A., H.R. and Z.Z. collected and analyzed patient's image data. All authors reviewed the manuscript.

## Additional Information

**Supplementary information** accompanies this paper at <http://www.nature.com/srep>

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