

# Preoperative color Doppler ultrasonography predicts early recurrence in AFP-positive hepatocellular carcinoma

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**Abstract.** The present study aimed to evaluate the hepatic hemodynamics of patients with  $\alpha$ -fetoprotein (AFP)-positive hepatocellular carcinoma (HCC) and early recurrence (ER), as determined by color Doppler ultrasound. Screening with color Doppler ultrasound was performed in 150 patients with AFP-positive HCC, yielding 43 cases with postoperative ER. In addition, 35 healthy controls were enrolled in the study for comparison of the blood flow parameters between the healthy control and the HCC groups. Receiver operating characteristic curve analysis was performed to evaluate the predicted effect of Doppler for the ER of HCC. The average mean flow velocity of portal vein in patients with HCC ( $14.686 \pm 5.873$  cm/s) was significantly lower in the HCC group compared with the healthy control group ( $17.631 \pm 3.569$  cm/s;  $P=0.005$ ). Additionally, the preoperative portal vein diameter in the HCC group was significantly higher compared with that in the healthy control group ( $P=0.001$ ). Regarding the effect of surgery, the portal vein diameter was significantly increased in the patients postoperatively compared with preoperatively ( $P=0.003$ ), while the pulsation and resistance indexes exhibited a decreasing trend in the postoperative group ( $P=0.001$  and  $P=0.003$ , respectively). Notably, patients with HCC and ER presented with a higher resistance index ( $1.163 \pm 0.342$ ) compared with

the ER-free group ( $1.023 \pm 0.176$ ;  $P=0.004$ ). Furthermore, a significant difference in hepatic artery pulsation index was also observed between the ER group ( $0.673 \pm 0.075$ ) and the ER-free group ( $0.624 \pm 0.056$ ;  $P=0.018$ ), indicating that an increased hepatic artery pulsation index may significantly predict the ER of HCC. In addition, areas under the curve of 0.683 and 0.700, respectively, suggested that the hepatic artery resistance and pulsation indexes may be used to diagnose ER in HCC ( $P=0.009$  and  $P=0.004$ , respectively). Taken together, Doppler ultrasound provides a reliable and accurate quantification of hepatic hemodynamics for detecting ER in HCC with a good diagnostic accuracy.

## Introduction

Hepatocellular carcinoma (HCC) is the sixth most common malignant tumor worldwide and one of the most common causes of cancer-associated mortality worldwide (1,2). Ultrasonography, computed tomography examination and serum  $\alpha$ -fetoprotein (AFP) levels are well-characterized approaches for the diagnosis of early HCC (3,4); however, prognosis of patients with HCC remains poor (5). Surgical resection is the preferred treatment for HCC (6). However, postoperative recurrence is the main cause of early mortality in patients with HCC following radical resection (7,8). Poon *et al* (9) reported that the prognosis of patients with HCC and early recurrence (ER; <1 year after surgical resection) is worse than that of patients with late recurrence (LR; >1 year), indicating that the shorter the interval time prior to recurrence, the worse the prognosis. Portolani *et al* (10) reported that the disease-free survival rate within 1 year following surgery is only 68.0%. As a result, the prediction of postoperative ER is particularly important, and therefore it was the main aim of the present study.

Ultrasound is considered the first choice for screening HCC due to its noninvasive, convenient and inexpensive imaging characteristics (11). Ultrasound can evaluate the size, number, position and boundary of tumor nodules, as well as monitoring hepatic hemodynamic changes. Cirrhosis is a serious liver disease, and advanced cirrhosis can easily develop into HCC (12). Doppler ultrasound has been used to detect hemodynamic changes that occur during the

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*Abbreviations:* HCC, hepatocellular carcinoma; AFP,  $\alpha$ -fetoprotein; ER, early recurrence; LR, late recurrence; ROC, receiver operating characteristic

*Key words:* color Doppler ultrasound, hepatocellular carcinoma, early recurrence, hepatic hemodynamics

progression and occurrence of hepatic fibrogenesis associated with cirrhosis (13). Previous research has demonstrated that Doppler ultrasound may be reliably used to assess hemodynamic changes in different stages of liver fibrosis (14). Furthermore, a study conducted by Suk *et al* (15) demonstrated that changes in hepatic hemodynamics may serve as a predictor for the clinical stages of HCC. Yang *et al* (16) proposed that the occurrence of HCC is associated with abnormal liver hemodynamics. Combined measurement of AFP levels and Doppler ultrasound has a greater diagnostic accuracy for HCC compared with ultrasonography alone. It has also been recognized that the diagnostic role of AFP together with abdominal ultrasound may effectively predict the risk of HCC development (17). However, to the best of our knowledge, the potential diagnostic value of preoperative Doppler ultrasound for ER of AFP-positive HCC has not been fully investigated thus far.

In the present study, the predicted value of hepatic hemodynamics for the ER of AFP-positive HCC was retrospectively assessed using Doppler ultrasound. Doppler ultrasound parameters were specifically evaluated in AFP-positive HCC and control groups. Furthermore, the present study investigated whether the hepatic artery and portal vein blood flow parameters were associated with postoperative ER of AFP-positive HCC.

## Materials and methods

**Clinical data.** The present study was performed with approval from the Ethics Committee of the Guangxi Medical University Affiliated Tumor Hospital and written informed consent was obtained from all participants. All the 150 patients with HCC received surgical treatment and were diagnosed by pathologists for the first time in the Guangxi Medical University Affiliated Tumor Hospital between September 2015 and December 2016. In total, the 137 AFP-positive patients with HCC (threshold, 400 ng/ml) were followed-up for 1 year following surgical treatment. The patients included 115 males and 22 females with a mean age of  $47.82 \pm 11.43$  years (range, 20-71 years). A total of 13 patients with AFP-positive HCC were lost to follow-up. Subsequently, the patients were divided into different groups according to their ER status, an ER group and an ER free group. The 35 healthy controls were enrolled from the outpatients department of the Guangxi Medical University Affiliated Tumor Hospital between September 2015 and December 2016 and consented to an ultrasound examination of their liver. The healthy controls included 20 males and 15 females, with a mean age of  $53.26 \pm 8.75$  years (range, 35-67 years).

**Ultrasound examination.** A standard ultrasonographic study was performed utilizing standard equipment (GE Logiq9 color Doppler; GE Healthcare Life Sciences) and a transducer ultrasound probe (2.5 or 3.5 MHz with low acoustic power). The enrolled subjects did not use drugs that affect hemodynamics (including nonselective  $\beta$ -blockers and vasopressin analogues) 5 days prior to the examination. Subjects were fasted for 6-8 h and allowed to rest for 30 min prior to the examination. Two-dimensional ultrasound images were used to evaluate the size, location, boundary, internal echo and blood flow of the liver-occupying lesions. The blood flow parameters of the

hepatic artery and portal vein were measured by color Doppler ultrasound. All of the subjects were laid flat and the ultrasonic probe was placed intercostally. The hepatic blood flow of the portal and hepatic arteries was detected between the neck of the gallbladder and the inferior vena cava. The following Doppler ultrasound parameters were measured: i) Portal vein blood flow of the mean flow velocity; ii) portal venous blood flow volume; iii) portal vein diameter; iv) hepatic artery pulsation index (PI); and v) hepatic artery resistance index (RI). To ensure reliability, all parameters were measured  $\geq 3$  times simultaneously and the mean value was calculated. When patients with HCC were followed up for 3 months following the operation, results were similar to the pre-operative exam. The tests were performed by two experienced ultrasound physicians, and conflicting opinions were discussed and resolved by a third physician.

**Statistical analysis.** All statistical analyses were performed using SPSS software (version 22.0; IBM Corp.). The results are presented as the mean  $\pm$  standard deviation. An independent Student's t-test was used for comparisons between two groups. A paired Student's t-test was utilized to compare hepatic hemodynamics changes in the preoperative and postoperative stages in the same patient. The Chi-squared test was used to analyze the qualitative data including sex, tumor number, tumor thrombi, liver cirrhosis and hepatitis. Receiver operating characteristic (ROC) curves were generated to evaluate the diagnostic accuracy of Doppler ultrasonography for ER in patients with HCC.  $P < 0.05$  was considered to indicate a statistically significant difference.

## Results

**Baseline characteristics.** A total of 150 patients (including 128 males and 22 females) with AFP-positive HCC and 35 healthy controls were recruited at the Affiliated Tumor Hospital of Guangxi Medical University (Nanning, China) between September 2015 and December 2016 (Table I). In total, 13 patients were lost to follow-up and 137 patients with AFP-positive HCC (mean age,  $48.360 \pm 11.482$  years) completed the follow-up. Among these patients, 41 cases were diagnosed with postoperative ER (ER group) and 96 cases were free of postoperative ER (ER-free group). The patients were classified into a liver cirrhosis group ( $n=61$ ) and a non-liver cirrhosis group ( $n=76$ ), according to their cirrhosis status. In the healthy control group, 20 males and 15 females were included. The characteristics of the patients are summarized in Table II.

**Change in hepatic hemodynamics between preoperative patients with HCC and healthy controls.** The change in hepatic hemodynamics between patients with HCC and the control group was evaluated (Fig. 1). The mean flow velocity ( $14.686 \pm 5.873$  cm/sec) in patients with HCC was significantly lower compared with that observed in healthy subjects ( $17.631 \pm 3.569$  cm/sec;  $P=0.005$ ; Fig. 2A). Additionally, the results revealed that patients with HCC presented with significantly higher portal vein diameters ( $1.085 \pm 0.149$  cm) compared with the healthy control group ( $0.991 \pm 0.155$  cm;  $P=0.001$ ; Fig. 2B). There was no statistical significance difference in the other parameters, including portal venous

Table I. Baseline pre-operative clinical characteristics of the enrolled patients.

Variables	n
Sex	
Male	128
Female	22
Age, years	
Mean $\pm$ SD	48.36 $\pm$ 11.48
Tumor number	
Multiple	47
Single	102
Tumor thrombi	
Yes	86
No	64
Tumor diameter (cm)	
Mean $\pm$ SD	7.58 $\pm$ 3.92
Liver cirrhosis	
Yes	68
No	82
Hepatitis	
Yes	143
No	7
Early recurrence	
Yes	41
No	96

SD, standard deviation.

flow velocity, portal venous volume, hepatic artery RI and PI, between the preoperative HCC group and the healthy control group (Table III).

#### *Effect of surgery on the hemodynamics of patients with HCC.*

The hemodynamic changes prior to and following the surgical procedure in patients with HCC were compared using paired Student's t-test. The portal vein diameter significantly increased upon operation (pre-operative, 1.07 $\pm$ 0.14 cm vs. post-operative, 1.14 $\pm$ 0.19 cm; P=0.003; Fig. 3A). The effect of surgery on the hepatic artery was evaluated. The results revealed that the PI presented the same trend in the post-operative group (pre-operative group, 1.095 $\pm$ 36.331 cm; post-operative group, 1.330 $\pm$ 0.260 cm; P=0.001; Fig. 3B). Additionally, the RI in the post-operative group (0.690 $\pm$ 0.060) was significantly higher compared with that observed in the pre-operative group (0.650 $\pm$ 0.080; P=0.003; Table IV; Fig. 3C).

#### *Comparison of hemodynamic changes between patients with HCC and postoperative ER and ER-free patients with HCC.*

The hemodynamic changes between the ER group (Fig. 4) and the ER-free group (Fig. 5) were compared. Notably, the post-operative ER group exhibited a significantly increased hepatic artery PI (0.673 $\pm$ 0.075 vs. 0.624 $\pm$ 0.056; P=0.018; Fig. 6A; Table V) compared with the ER-free group. Furthermore, a

Table II. Clinical characteristics of ER and ER-free patients.

Variables	ER group, n	ER-free group, n	P-value
Sex			
Male	37	78	0.216
Female	4	18	
Age, years			
Mean $\pm$ SD	46.34 $\pm$ 11.410	48.45 $\pm$ 11.439	0.325
Tumor number			
Multiple	15	28	0.419
Single	25	68	
Tumor thrombi			
Yes	28	51	0.131
No	13	45	
Tumor diameter (cm)			
Mean $\pm$ SD	9.25 $\pm$ 3.621	6.82 $\pm$ 3.628	<0.05 <sup>a</sup>
Liver cirrhosis			
Yes	22	39	0.190
No	19	57	
Hepatitis			
Yes	41	90	0.178
No	0	6	

<sup>a</sup>P<0.05 was considered to indicate a statistically significant difference. ER, early recurrence; SD, standard deviation.

statistically significant difference in RI was observed between the ER and ER-free groups, indicating that the RI in the ER group (1.163 $\pm$ 0.342) was significantly lower than that of the ER-free group (1.023 $\pm$ 0.176; P=0.004; Fig. 6B, Table V). For the other parameters measured, including average flow velocity, portal venous blood flow volume and portal vein diameter, no statistically significant differences were observed between the ER group and the ER-free group (Table V).

#### *Diagnostic accuracy of Doppler ultrasonography for the diagnosis of ER in HCC.*

ROC curve analysis was performed to assess the diagnostic accuracy of Doppler ultrasonography for the diagnosis of ER in patients with HCC. The area under the ROC curve (AUC) of preoperative RI value was 0.683 (range, 0.564-0.801; P=0.009). An AUC value for RI of 0.645 corresponded with the highest diagnostic value for ER with a sensitivity of 68% and a specificity of 70.91% (Fig. 7A). As for the preoperative PI, an AUC of 0.700 suggested a high diagnostic accuracy of preoperative PI for the ER of patients with HCC (range, 0.583-0.818; P=0.004). The best cut-off value of pre-operative PI was 1.045, with a sensitivity of 72.00% and a specificity of 67.27% (Table VI; Fig 7B).

## Discussion

Surgical resection is the first choice for the treatment of HCC. However, recurrence subsequent to resection is one of the main factors affecting the prognosis of HCC (18).

Table III. Blood flow parameters of the portal vein and hepatic artery in health controls and patients with HCC.

Variable	Healthy control group			HCC group			P-value
	n	Mean	SD	n	Mean	SD	
<b>Hepatic artery</b>							
RI	35	0.663	0.048	86	0.654	0.077	0.524
PI	35	1.185	0.217	86	1.1116	0.306	0.442
<b>Portal vein</b>							
V, cm/s	35	17.631	3.569	146	14.686	5.873	0.005 <sup>a</sup>
Q, ml/min	35	466.349	165.623	150	535.635	229.640	0.094
D, cm	35	0.991	0.155	150	1.085	0.149	0.001 <sup>a</sup>

<sup>a</sup>P<0.05 was considered to indicate a statistically significant difference. HCC, hepatocellular carcinoma; SD, standard deviation; RI, resistance index; PI, pulsation index; V, average flow velocity; Q, portal venous blood flow volume; D, portal vein diameter.

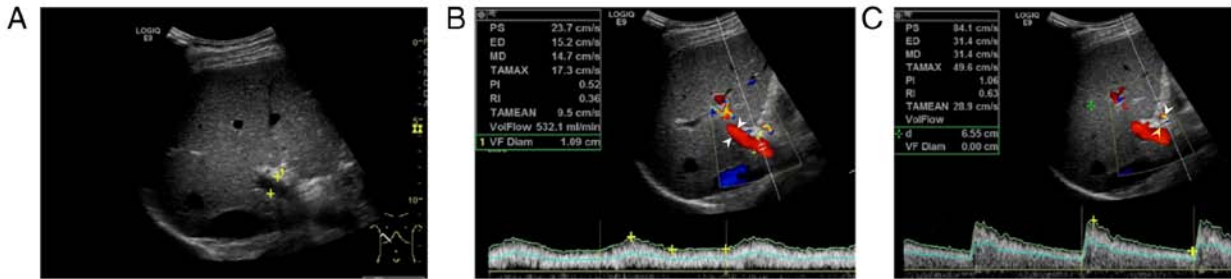


Figure 1. Results from a 50-year-old healthy control. (A) Two-dimensional ultrasound image. (B) Color Doppler blood flow diagram of the portal vein (D, 1.09 cm; V, 14.7 cm/sec; Q, 532.1 ml/min). (C) Color Doppler blood flow diagram of the hepatic artery (white arrowheads; PI, 1.06; RI, 0.63). PS, peak systolic velocity; ED, end-diastolic velocity; VF Diam, portal vein diameter; MD, average flow velocity; VolFlow, portal venous blood flow volume; TAMEAN, time averaged velocity; TAMAX, mean time maximum velocity.

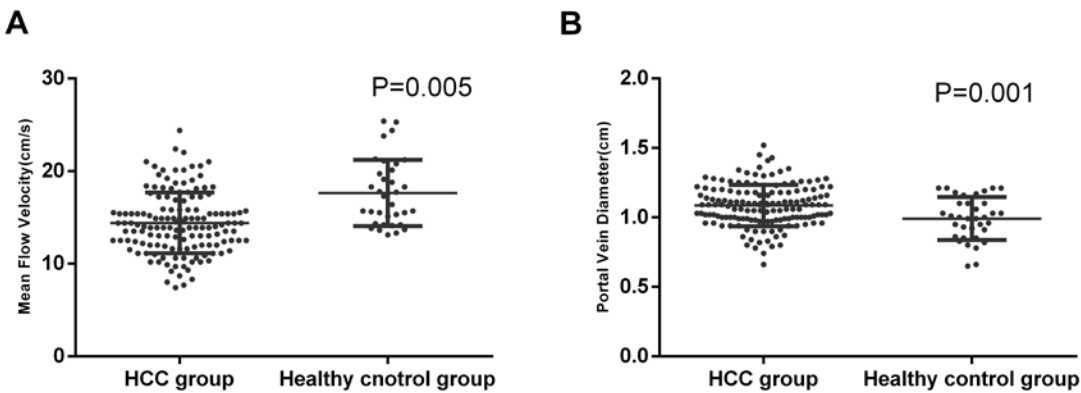


Figure 2. Comparison of the hepatic hemodynamics between the hepatocellular carcinoma group and the healthy control group. (A) Mean flow velocity. (B) Portal vein diameter.

It has become evident that post-operative recurrence of HCC can be classified into ER and LR (8,9). In particular, ER presents challenges for the treatment of liver cancer. Colecchia *et al* (19) demonstrated that ER may originate from the liver metastasis of primary tumors, which is mainly associated with biological factors of the tumor, including tumor size, number of lesions and vascular invasion. LR is caused by the residual liver state, and is affected by the history of

HCC prior to treatment and the presence of hepatitis and cirrhosis (20). A reliable and effective prediction method to assess the risk of HCC recurrence may shed light on future treatment strategies.

The examination of blood vessels morphology and hemodynamics may directly or indirectly reflect the inherent biological characteristics of tumors (21). As a noninvasive imaging modality, ultrasonography is widely used in routine clinical

Table IV. Changes of the blood flow parameters of the portal vein pre- and post-surgery in patients with hepatocellular carcinoma.

Variable	Pre-operative			Post-operative			P-value
	n	Mean	SD	n	Mean	SD	
<b>Portal vein</b>							
V, cm/s	107	14.680	6.540	107	13.988	3.748862749	0.287
Q, ml/min	107	526.190	245.810	107	531.600	230.780	0.868
D, cm	107	1.070	0.140	107	1.140	0.190	0.003 <sup>a</sup>
<b>Hepatic artery</b>							
PI	36	1.100	0.330	36	1.330	0.260	0.001 <sup>a</sup>
RI	36	0.650	0.080	36	0.690	0.060	0.003 <sup>a</sup>

<sup>a</sup>P<0.05 was considered to indicate a statistically significant difference. SD, standard deviation; RI, resistance index; PI, pulsation index; V, average flow velocity; Q, portal venous blood flow volume; D, portal vein diameter.

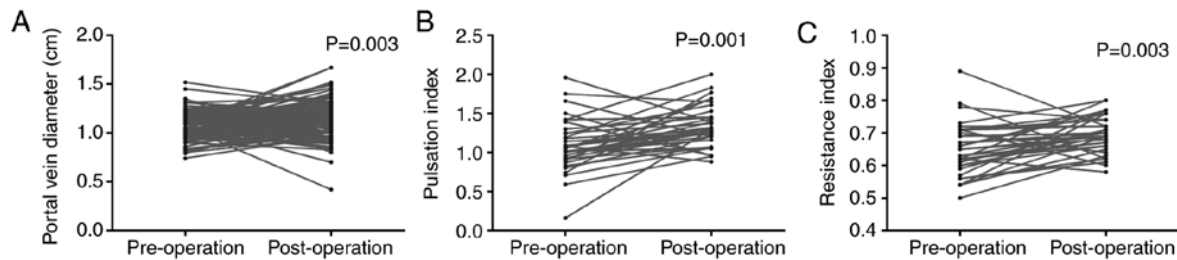


Figure 3. Changes in the hepatic hemodynamics in patients with hepatocellular carcinoma pre- and post-operatively. (A) Portal vein diameter. (B) Pulsation index. (C) Resistance index.

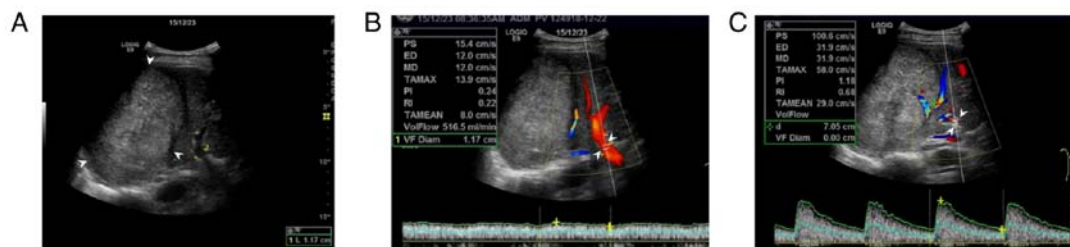


Figure 4. Results from a 45-year-old patient with hepatocellular carcinoma, positive  $\alpha$ -fetoprotein, liver cirrhosis, Child-Pugh A, tumor pathological stage of intermediate differentiation, Barcelona clinic liver cancer stage B and postoperative early recurrence. (A) Conventional ultrasound image revealing a 14 cm-diameter lesion tumor (white arrowhead). (B) Color Doppler blood flow diagram of the portal vein (white arrowheads; D, 1.17 cm; V, 12.0 cm/sec; Q, 516.5 ml/min). (C) Color Doppler blood flow diagram of the hepatic artery (white arrowheads; PI, 1.18; RI, 0.68). PS, peak systolic velocity; ED, end-diastolic velocity; MD, average flow velocity; VolFlow, portal venous blood flow volume; VF Diam, portal vein diameter; PI, pulsation index; RI, resistance index; TAMEAN, time averaged velocity; TAMAX, mean time maximum velocity.

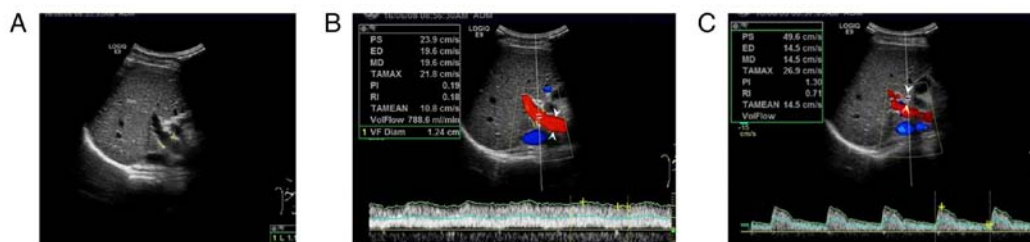


Figure 5. Results from a 65-year-old patient with hepatocellular carcinoma, positive  $\alpha$ -fetoprotein, no liver cirrhosis, Child-Pugh A, tumor pathological stage of intermediate differentiation, tumor emboli, Barcelona clinic liver cancer stage C and no early recurrence following surgery. (A) Conventional ultrasound image revealing no early recurrence following surgery. (B) Color Doppler blood flow diagram of the portal vein (white arrowheads; D, 1.24 cm; V, 19.6 cm/sec; Q, 788.6 ml/min). (C) Color Doppler blood flow diagram of the hepatic artery (white arrowheads; PI, 1.30; RI, 0.71). PS, peak Systolic velocity; ED, end-diastolic velocity; MD, average flow velocity; Vloflow, portal venous blood flow volume; VF Diam, portal vein diameter; PI, pulsation index; RI, resistance index, TAMEAN, time averaged velocity; TAMAX, mean time maximum velocity.

Table V. Blood flow parameters of the portal vein and hepatic artery in the ER-free group and ER group of patients with hepatocellular carcinoma.

Variables	ER-free group			ER group			P-value
	n	Mean	SD	n	Mean	SD	
<b>Hepatic artery</b>							
RI	25	1.023	0.176	55	1.163	0.342	0.004 <sup>a</sup>
PI	25	0.624	0.056	55	0.673	0.075	0.018 <sup>a</sup>
<b>Portal vein</b>							
V, cm/s	96	14.725	6.827	37	14.284	3.261	0.687
Q, ml/min	96	520.685	244.144	41	538.344	210.213	0.708
D, cm	96	1.067	0.15	41	1.1	0.14	0.233

<sup>a</sup>P<0.05 was considered to indicate a statistically significant difference. ER, early recurrence; SD, standard deviation; RI, resistance index; PI, pulsation index; V, average flow velocity; Q, portal venous blood flow volume; D, portal vein diameter.

Table VI. Receiver operating characteristic curve analysis of PI and RI for the diagnosis of ER in patients with hepatocellular carcinoma.

Variables	Area under the curve (range)	P-value	Cut-off	Sensitivity, %	Specificity, %
RI	0.683 (0.564-0.801)	0.009	<0.6450	68.00	70.91
PI	0.700 (0.583-0.818)	0.004	<1.0450	72.00	67.27

RI, resistance index; PI, pulsation index; ER, early recurrence.

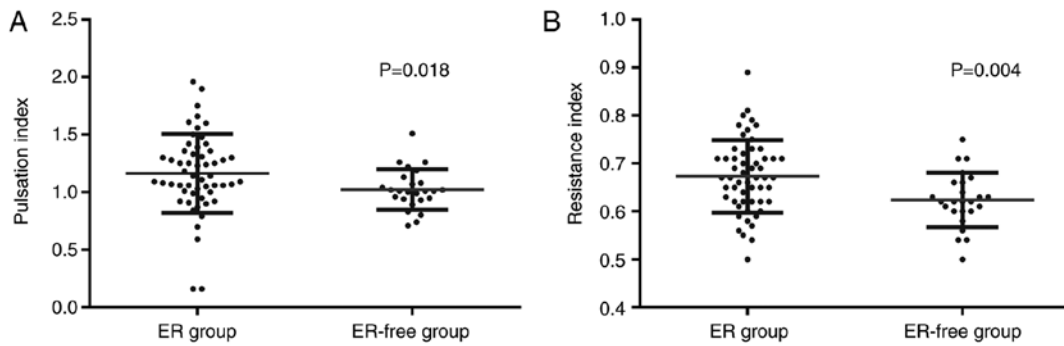


Figure 6. Differences in hepatic hemodynamics between the ER group and the ER-free group. (A) Pulsation index. (B) Resistance index. ER, early recurrence.

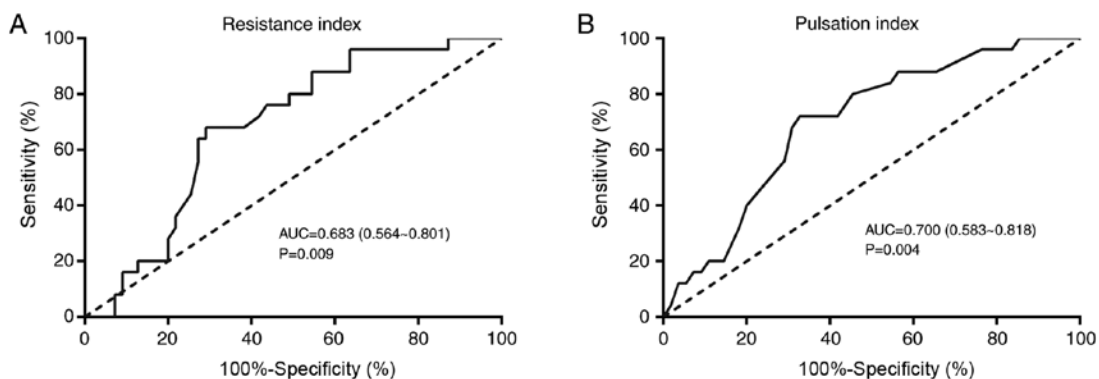


Figure 7. Predicted value of hepatic artery parameters for the early recurrence of hepatocellular carcinoma in patients. (A) Resistance index and (B) pulsation index. AUC, area under the curve.

practice for diagnosis, treatment planning or monitoring of cancer, particularly for detecting changes in hemodynamics of the portal vein and hepatic artery (22-25). Therefore, it was speculated that the hemodynamics of ultrasound detection may be a valuable predictor for the ER of HCC following resection. It has been demonstrated that the combination of ultrasonography and measurement of AFP levels confers the efficient surveillance strategy for early HCC detection (26). Previous studies have demonstrated that the factors affecting the recurrence of HCC include incomplete or absent tumor capsule, preoperative AFP levels >400 ng/l, lesion size and positive pathological margin (25,27-30). Clinically, the size and capsule of HCC tumors may be assessed by various imaging methods prior to surgery, while the AFP levels can be detected through laboratory examination. However, pathological grading of tumors and microvascular invasion cannot be obtained prior to pathological examination. Therefore, the prediction of ER of HCC requires future investigation to improve patient prognosis (3). The present study focused on patients with AFP-positive HCC to investigate the diagnostic value of ultrasonography for the recurrence of HCC (31).

Comparison of the hemodynamics between patients with HCC and healthy controls revealed that the pre-operative portal venous blood flow volume and portal vein diameter in patients with HCC were significantly increased compared with the control group, while the preoperative hepatic artery PI in patients with HCC was significantly decreased compared with the control group. The present study demonstrated that monitoring of the hepatic hemodynamics is important for the early diagnosis of HCC recurrence. To the best of our knowledge, no studies on this topic have been conducted thus far. The results obtained in the present study revealed that pre-operative hepatic artery RI and PI in the ER group were significantly lower compared with in the ER-free group. In addition, the ROC curve revealed that pre-operative PI <1.05 and RI <0.645 may be used as reference values for predicting the occurrence of ER in postoperative HCC. Bonnin *et al* (32) revealed that the hepatic artery Doppler perfusion index was established earlier during the diagnosis of liver cancer when compared with conventional ultrasonography (37.6±12.7 days), and that increased blood flow in the hepatic artery may be used to monitor the growth of liver tumors in mice, leading to a diagnosis of liver cancer 4-20 weeks earlier.

Blood to the liver is supplied by the hepatic artery and portal vein. Advanced liver cirrhosis is associated with portal hypertension and portal vein widening, with the majority of cases progressing into HCC. The histopathology of HCC revealed the presence of neovasculature and blood pooling in the tumor. Compared with the same diameter hepatic artery, the lower number of elastic fibers in patients with HCC contributes to a lower hepatic artery blood flow resistance and faster flow rate. In conclusion, the pathological changes of HCC are accompanied by changes in the hemodynamics of the hepatic artery and portal vein (33). Therefore, the early dynamic changes of the hepatic artery and portal vein may be used to predict recurrence in HCC. The application of color Doppler ultrasound for hepatic artery and portal venous hemodynamics is particularly useful for the early diagnosis of HCC recurrence.

HCC tumor blood is mainly supplied by the hepatic artery, while the portal vein is involved in the peripheral part of the liver and extends to the center with a small branch (34). When the tumor size is >5 cm, the hepatic artery and portal vein are intertwined to form a vascular lake around the tumor, whereas the tumor blood supply is partially or completely derived from the portal vein when the tumor size is <5 cm (35-37). The portal venous system has multiple collateral circulations and may exhibit a small blood flow in HCC with ER (37,38). Therefore, the hepatic artery affects HCC tumor recurrence more than the portal vein, resulting in no significant changes when the latter is monitored by current ultrasound instrumentation. Hepatic artery PI and RI are the main parameters to reflect the blood flow of the hepatic artery. The hepatic artery hemodynamic changes in liver cancer were previously evaluated by RI and PI in the literature. The PI and RI measurements of the hepatic artery are highly reproducible, easily measured and not affected by the changes in respiration or body position (39). In addition, the ultrasonic detection of PI and RI can be fully quantified. Therefore, the PI and RI of the hepatic artery may be predictors of ER following surgery in HCC.

The present study had several limitations. Firstly, The PI value is affected by heart rate, hemangiectasis ability and the total resistance of peripheral blood vessels (40). Secondly, the limits of the instrument and the operator may lead to discrepancy in the observations. Finally, the retrospective nature and small sample size of the present study may lead to statistical type-II errors. Overall, the sensitivity and specificity of ultrasonic monitoring require improvement. In conclusion, the present study indicated that color Doppler ultrasound detection of hepatic hemodynamics may have significant value for the diagnosis of ER in HCC. It may significantly improve the accuracy of predicting the occurrence of preoperative ER, which may assist clinicians in selecting optimal treatment strategies for patients with HCC.

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#### Availability of data and materials

All data generated or analyzed during the present study are included in this published article.

#### Authors' contributions

HL designed the study and revised the manuscript. JL participated in designing and conducting the research. MC conceived the research and contributed to manuscript writing. DW and DL collected and analyzed the data. YZ and HL analyzed the data and interpreted the results.

### Ethics approval and consent to participate

The present study was performed with approval of the Ethics Committee of the Guangxi Medical University Affiliated Tumor Hospital and written informed consent was obtained from all participants.

### Patient consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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